2001 ASME BOILER & PRESSURE VESSEL CODE

V

AN INTERNATIONAL CODE

The American Society of Mechanical Engineers

NONDESTRUCTIVE EXAMINATION

ASME BOILER AND PRESSURE VESSEL CODE
AN INTERNATIONAL CODE

V

NONDESTRUCTIVE EXAMINATION

2001 Edition
July 1, 2001

ASME BOILER AND PRESSURE VESSEL COMMITTEE
SUBCOMMITTEE ON NONDESTRUCTIVE EXAMINATION

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2001 ASME
BOILER AND PRESSURE VESSEL CODE

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ADDENDA

Colored-sheet Addenda, which include additions and revisions to individual Sections of the Code, are published annually and will be sent automatically to purchasers of the applicable Sections up to the publication of the 2004 Code. The 2001 Code is available only in the loose-leaf format; accordingly, the Addenda will be issued in the loose-leaf, replacement-page format.

INTERPRETATIONS

ASME issues written replies to inquiries concerning interpretation of technical aspects of the Code. The Interpretations for each individual Section will be published separately and will be included as part of the update service to that Section. They will be issued semiannually (July and December) up to the publication of the 2004 Code. Interpretations of Section III, Divisions 1 and 2, will be included with the update service to Subsection NCA.

CODE CASES

The Boiler and Pressure Vessel Committee meets regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases which have been adopted will appear in the appropriate 2001 Code Cases book: (1) Boilers and Pressure Vessels and (2) Nuclear Components. Supplements will be sent automatically to the purchasers of the Code Cases books up to the publication of the 2004 Code.

CONTENTS

A Detailed Contents Precedes Subsections A and B, and the Appendices

FOREWORD

The American Society of Mechanical Engineers set up a committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. This committee is now called the Boiler and Pressure Vessel Committee.

The Committee's function is to establish rules of safety governing the design, fabrication, and inspection during construction of boilers and pressure vessels, and to interpret these rules when questions arise regarding their intent. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of pressure vessels. The objective of the rules is to afford reasonably certain protection of life and property and to provide a margin for deterioration in service so as to give a reasonably long, safe period of usefulness. Advancements in design and material and the evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction[1] activities. The Code does not address all aspects of these activities and those aspects which are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable designers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and they are responsible for the application of these programs to their design.

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practices as determined by the designer.

The Boiler and Pressure Vessel Committee deals with the care and inspection of boilers and pressure vessels in service only to the extent of providing suggested rules of good practice as an aid to owners and their inspectors.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Boiler and Pressure Vessel Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Boiler and Pressure Vessel Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Mandatory Appendix covering preparation of technical inquiries). Proposed revisions to the Code resulting from inquiries will be presented to the Main Committee for appropriate action. The action of the Main Committee becomes effective only after confirmation by letter ballot of the Committee and approval by ASME.

Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute and published in *Mechanical Engineering* to invite comments from all interested persons. After the allotted time for public review and final

[1] *Construction*, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

approval by ASME, revisions are published annually in Addenda to the Code.

Code Cases may be used in the construction of components to be stamped with the ASME Code symbol beginning with the date of their approval by ASME.

After Code revisions are approved by ASME, they may be used beginning with the date of issuance shown on the Addenda. Revisions, except for revisions to material specifications in Section II, Parts A and B, become mandatory 6 months after such date of issuance, except for boilers or pressure vessels contracted for prior to the end of the 6 month period. Revisions to material specifications are originated by the American Society for Testing and Materials (ASTM), and other recognized national or international organizations and are usually adopted by ASME. However, those revisions may or may not have any effect on the suitability of material, produced to earlier editions of specifications, for use in ASME construction. ASME material specifications approved for use in each construction Code are listed in the Appendices of Section II, Parts A and B. These Appendices list, for each specification, the latest edition adopted by ASME, and earlier and later editions considered by ASME to be identical for ASME construction.

Manufacturers and users of components are cautioned against making use of revisions and Cases that are less restrictive than former requirements without having assurance that they have been accepted by the proper authorities in the jurisdiction where the component is to be installed.

Each state and municipality in the United States and each province in Canada that adopts or accepts one or more Sections of the Boiler and Pressure Vessel Code is invited to appoint a representative to act on the Conference Committee to the Boiler and Pressure Vessel Committee. Since the members of the Conference Committee are in active contact with the administration and enforcement of the rules, the requirements for inspection in this Code correspond with those in effect in their respective jurisdictions. The required qualifications for an Authorized Inspector under these rules may be obtained from the administrative authority of any state, municipality, or province which has adopted these rules.

The Boiler and Pressure Vessel Committee in the formulation of its rules and in the establishment of maximum design and operating pressures considers materials, construction, methods of fabrication, inspection, and safety devices. Permission may be granted to regulatory bodies and organizations publishing safety standards to use a complete Section of the Code by reference. If usage of a Section, such as Section IX, involves exceptions, omissions, or changes in provisions, the intent of the Code might not be attained.

Where a state or other regulatory body, in the printing of any Section of the Boiler and Pressure Vessel Code, makes additions or omissions, it is recommended that such changes be clearly indicated.

The National Board of Boiler and Pressure Vessel Inspectors is composed of chief inspectors of states and municipalities in the United States and of provinces in Canada that have adopted the Boiler and Pressure Vessel Code. This Board, since its organization in 1919, has functioned to uniformly administer and enforce the rules of the Boiler and Pressure Vessel Code. The cooperation of that organization with the Boiler and Pressure Vessel Committee has been extremely helpful.

The Code Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The Scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules. Laws or regulations issued by municipality, state, provincial, federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the Code rules, in whole or in part, within their jurisdiction. Those laws or regulations may require the use of this Code for vessels or components not considered to be within its Scope or may establish additions or deletions in that Scope. Accordingly, inquiries regarding such laws or regulations are to be directed to the issuing enforcement or regulatory body.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the ASME Boiler and Pressure Vessel Committee. ASME is to be notified should questions arise concerning improper use of an ASME Code symbol.

The specifications for materials given in Section II are identical with or similar to those of the Specifications published by ASTM, AWS, and other recognized national or international organizations. When reference is made in an ASME material specification to a non-ASME specification for which a companion ASME specification exists, the reference shall be interpreted as applying to the ASME material specification. Not all materials included in the material specifications in Section II have been adopted for Code use. Usage is limited to those materials and grades adopted by at least one of the other Sections of the Code for application under rules of that Section. All materials allowed by these various Sections and used for construction

within the scope of their rules shall be furnished in accordance with material specifications contained in Section II or referenced in Appendices A of Section II, Parts A and B except where otherwise provided in Code Cases or in the applicable Section of the Code. Materials covered by these specifications are acceptable for use in items covered by the Code Sections only to the degree indicated in the applicable Section. Materials for Code use should preferably be ordered, produced, and documented on this basis; Appendix A to Section II, Part A and Appendix A to Section II, Part B list editions of ASME and year dates of specifications that meet ASME requirements and which may be used in Code construction. Material produced to an acceptable specification with requirements different from the requirements of the corresponding specifications listed in Appendix A of Part A or Part B may also be used in accordance with the above, provided the material manufacturer or vessel manufacturer certifies with evidence acceptable to the Authorized Inspector that the corresponding requirements of specifications listed in Appendix A of Part A or Part B have been met. Material produced to an acceptable material specification is not limited as to country of origin.

When required by context in this Section, the singular shall be interpreted as the plural, and vice-versa; and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

Publication of the SI (Metric) Edition of the ASME Boiler and Pressure Vessel Code was discontinued with the 1986 Edition. Effective October 1, 1986, the SI Edition was withdrawn as an ASME Boiler and Pressure Vessel Code document.

STATEMENT OF POLICY ON THE USE OF CODE SYMBOLS AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use Code Symbols for marking items or constructions which have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Code Symbols for the benefit of the users, the enforcement jurisdictions, and the holders of the symbols who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the symbols, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications which might so indicate. An organization holding a Code Symbol and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code."

The ASME Symbol shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of a Code Symbol who may also use the facsimile in advertising to show that clearly specified items will carry the symbol. General usage is permitted only when all of a manufacturer's items are constructed under the rules.

The ASME logo, which is the cloverleaf with the letters ASME within, shall not be used by any organization other than ASME.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Code Symbol Stamp described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the various Code Symbols shall not be used on any item which is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME which tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

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As of December 31, 2000

E-7 ON NONDESTRUCTIVE TESTING

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The 2001 Edition of the Code contains both U.S. Customary and SI units. In all cases, the U.S. Customary units are the standard and SI units are provided for the convenience of the user.

SUMMARY OF CHANGES

The 2001 Edition of this Code contains revisions in addition to the 1998 Edition with 1999 and 2000 Addenda. The revisions are identified with the designation **01** in the margin and, as described in the Foreword, become mandatory six months after the publication date of the 2001 Edition. To invoke these revisions before their mandatory date, use the designation "2001 Edition" in documentation required by this Code. If you choose not to invoke these revisions before their mandatory date, use the designation "1998 Edition through the 2000 Addenda" in documentation required by this Code.

Changes given below are identified on the pages by a margin note, **01**, placed next to the affected area.

Page	*Location*	*Change*
12	Footnote 3	Corrected by Errata
16	Article 2 Contents	Updated to reflect 01
21	T-221.1	Title deleted and paragraph revised
24	T-272	Revised in its entirety
29	T-285	Note revised by Errata
	T-286	Last sentence corrected by Errata
44–45	VI-A-220	Title revised
	VI-A-230	Title revised
	VI-A-232.1	Title added
	VI-A-232.2	Title added
	VI-A-233	(1) Old VI-A-232.3 redesignated as VI-A-233 (2) Title added
	VI-A-234	(1) Old VI-A-232.4 redesignated as VI-A-234 (2) Title added
	VI-A-235	(1) Old VI-A-232.5 redesignated as VI-A-235 (2) Title added
	VI-A-240	Title revised
	VI-A-244	Paragraph references updated
63	T-423	New paragraph added
101	T-522	Title and paragraph revised
102	T-541.1	Subparagraphs (a)–(d) revised
	T-541.2	Subparagraphs (a) and (b) revised
103	T-541.3	Subparagraphs (a) and (b) revised
115	T-544(a), (b)	Cross-references revised
116	III-520	Subparagraph (c) corrected by Errata
122	T-610.1	Revised in its entirety
	T-621	Title revised
	T-621.1	Title deleted and paragraph revised
129	Article 7 Contents	Updated to reflect 01

Page	*Location*	*Change*
132	T-750	Revised in its entirety
137	T-778.1	Revised in its entirety
141	Appendix III	Added
147–148	T-810	Revised in its entirety
	T-821	Revised in its entirety
	T-822	Revised in its entirety
	T-823	Revised in its entirety
	Table T-823	Added
	T-830	Paragraph added
	T-831	Revised in its entirety
	T-832	Added
	T-833	Added
	T-850	Added
	T-861	Revised in its entirety
	T-862	Added
	T-870	Added
149	T-880	Paragraph added
	T-890	Paragraph T-881 revised and redisgnated as T-890
	T-891	Added
	T-892	Added
157	II-860.1.1	Subparagraph (f) revised
160	III-810	Revised in its entirety
	III-822	Added
	III-823	Added
	III-850	Title revised
	III-851	Revised in its entirety
	III-852	(1) Old III-852 deleted (2) Old III-853 redesignated as III-852
161	III-890	Revised in its entirety
	III-891	Added
	III-892	Added
164–165	T-910	Revised in its entirety
	T-921	Revised in its entirety
	T-922	Added
	T-923	Added
	Table T-923	Added
	T-930	Added
	T-940	Title revised
	T-941	Title revised
	T-941.1	Revised in its entirety
	T-950	Title revised
	T-952	Revised in its entirety
166	T-954	Last sentence deleted
	T-980.2	Revised
	T-990	Title revised
	T-991	Revised in its entirety
	T-992	(1) New T-992 added

Page	Location	Change
		(2) Old T-992 redesignated as T-993
167	I-920	(1) Definition for *lux* added (2) Revised
173	T-1010	(1) Titles for Appendices IX and X added (2) Appendix references updated
	T-1021	Revised
	T-1031	Revised
174	T-1040	Title revised
	T-1050	Title revised
	T-1052	Revised in its entirety
	T-1063.1	Revised
177–180	I-1080	Revised in its entirety
	II-1080	Revised in its entirety
	III-1061	Revised in its entirety
	III-1062	Revised
	III-1063	Revised
	III-1064	(1) New III-1064 added (2) Old III-1064 revised and redesignated as III-1065
181–184	III-1077	Revised
	III-1078.2	Revised
	III-1080	Revised in its entirety
	IV-1061.2	Revised in its entirety
	IV-1061.3	Deleted
	IV-1062.1	Revised in its entirety
	IV-1062.2	Revised in its entirety
	IV-1062.3	Revised in its entirety
	IV-1062.4	(1) Old IV-1062.4 deleted (2) Old IV-1062.5 redesignated as IV-1062.4
	IV-1073	Revised
	IV-1077	Revised
	IV-1078.2	Revised
	IV-1080	Revised in its entirety
	Appendix V	Appendix title revised
	V-1010	Revised in its entirety
	V-1031	Revised
	V-1032	(1) Subparagraph (e) deleted (2) Subparagraph (f) redesignated as (e)
	V-1033	Revised in its entirety
	V-1061.2	Revised in its entirety
	V-1062.1	Revised
	V-1062.2	(1) New title added (2) Subparagraph revised
	V-1062.3	(1) New title added (2) Subparagraph revised
	V-1062.4	Added
	V-1062.5	Old V-1062.2 redesignated as V-1062.5
	V-1071	(1) Old V-1071 deleted (2) Old V-1071.1 revised and redesignated as V-1071

Page	*Location*	*Change*
	V-1072	(1) Old V-1072 Deleted (2) Old V-1071.2 revised and redesignated as V-1072
	V-1073	Old V-1071.3 revised and redesignated as V-1073
	V-1074	Old V-1071.4 revised and redesignated as V-1074
	V-1075	Added
	V-1080	Revised in its entirety
186	VII-1020	Revised in its entirety
	VII-1030	Paragraph designator deleted
188	VIII-1061	Revised
	VIII-1062	Revised
	VIII-1063	Revised
	VIII-1064	(1) New VIII-1064 added (2) Old VIII-1064 revised and redesignated as VIII-1065
189	VIII-1077	Revised
	VIII-1078.2	Revised
	VIII-1080	Revised in its entirety
190	Appendix IX	Added
193	Appendix X	Added
195	A-10	Revised in its entirety
199	T-1128	Title and paragraph revised
223	T-1225	Title and paragraph revised
247	T-1350	Title and paragraph revised
264	Article 22 Contents	Updated to reflect 01
280	SE-142	Deleted
281	SE-186	Deleted
282	SE-242	Deleted
283	SE-280	Deleted
284	SE-446	Deleted
365	SE-1647	Updated to reflect ASTM E 1647-98a
444	Article 24 Contents	Updated to reflect 01
489	SE-1209	Deleted
490	SE-1219	Deleted
491	SE-1220	Deleted
536	Article 26 Contents	Updated to reflect 01
537	SE-215	Deleted
545	SE-309	Deleted
546	SE-426	Deleted
547	SE-571	Deleted
601	Article 30 Contents	Updated to reflect 01
602	SE-1316	Updated to reflect ASTM E 1316-99

Subsection A

Nondestructive Methods of Examination

SUBSECTION A

Nonmandatory Appendices

Figures

Mandatory Appendices

Nonmandatory Appendices

ARTICLE 1

ARTICLE 1
GENERAL REQUIREMENTS

T-110 SCOPE

(a) Unless otherwise specified by the referencing Code Section or other referencing documents, this Section of the Code contains requirements and methods for nondestructive examination which are Code requirements to the extent they are specifically referenced and required by other Code Sections. These nondestructive examination methods are intended to detect surface and internal discontinuities in materials, welds, and fabricated parts and components. They include radiographic examination, ultrasonic examination, liquid penetrant examination, magnetic particle examination, eddy current examination, visual examination, leak testing, and acoustic emission examination.

(b) For general terms such as *Inspection, Flaw, Discontinuity, Evaluation*, etc., refer to Mandatory Appendix I.

T-120 GENERAL

(a) Subsection A describes the methods of nondestructive examination to be used if referenced by other Code Sections.

(b) Subsection B lists Standards covering nondestructive examination methods which have been accepted as standards. These standards are intended to be informative only and are nonmandatory unless specifically referenced in whole or in part in Subsection A or as indicated in other Code Sections.

(c) Reference to a paragraph of any Article in Subsection A of this Section or in the referencing Code Section includes all of the applicable rules in the paragraph.[1] In every case, reference to a paragraph includes all the subparagraphs and subdivisions under that paragraph.

(d) Reference to a Standard contained in Subsection B is mandatory only to the extent specified in an Article of Subsection A or as specified in other Code Sections.[2]

T-130 EQUIPMENT

It is the responsibility of the Manufacturer, fabricator, or installer to ensure that the examination equipment being used conforms to the requirements of this Code Section.

T-140 REQUIREMENTS 01

(a) Nondestructive Examination Personnel shall be qualified in accordance with the requirements of the referencing Code Section.

(b) For those Code Sections that directly reference this Article for the qualification of NDE personnel, the qualification shall be in accordance with one of the following documents:

(1) SNT-TC-1A,[3] Personnel Qualification and Certification in Nondestructive Testing; or

(2) ANSI/ASNT CP-189,[3] ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel; or

(3) ACCP,[3] ASNT Central Certification Program.

(c) When the referencing Code Section does not specify qualifications or does not reference directly Article 1 of this Section, qualification may simply involve demonstration in routine manufacturing operations to show that the personnel performing the nonde-

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[1] For example, reference to T-270 includes all the rules contained in T-271 through T-277.3.

[2] For example, T-233 requires that Image Quality Indicators be manufactured and identified in accordance with the requirements or alternatives allowed in SE-747 or SE-1025, and Appendices, as appropriate for the style of IQI to be used. These are the only parts of either SE-747 or SE-1025 that are mandatory in Article 2.

[3] SNT-TC-1A (1996 Edition, with 1998 Addendum), "Personnel Qualification and Certification in Nondestructive Testing;" ANSI/ASNT CP-189 (1995 Edition), "ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel;" and ACCP [Revision 3 (November 1997)], "ASNT Central Certification Program;" published by the American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, Ohio 43228-0518.

:aminations are competent to do so in accord-
the Manufacturer's established procedures.
certificate holder shall ensure that NDE
ıre qualified and certified in accordance with
:. The certificate holder's Quality Program
ate how this is to be accomplished.
ifications in accordance with a prior edition
C-1A, CP-189, or ACCP are valid until
on. Recertification or new certification shall
·dance with the edition of SNT-TC-1A, CP-
CCP specified in footnote 3.
ted certification of nondestructive examina-
nel who do not perform all of the operations
structive method that consists of more than
on, or who perform nondestructive examina-
nited scope, may be based on fewer hours
and experience than recommended in SNT-
P-189, or ACCP. Any limitations or restric-
:d upon a person's certification shall be
n the written practice and on the certification.
SNT-TC-1A document is a guide to establish
or training, qualification, and certification of
onnel as required by the referencing Code

PROCEDURE

nondestructive examination methods included
ion are applicable to most geometric configu-
l materials encountered in fabrication under
ıditions. However, special configurations and
ıay require modified methods and techniques,
:ase the Manufacturer shall develop special
which are equivalent or superior to the
ıd techniques described in this Code Section,
are capable of producing interpretable exami-
lts under the special conditions. Such special
may be modifications or combinations of
escribed or referenced in this Code Section,
be proved by demonstration to be capable
g discontinuities under the special conditions,
lemonstrated capabilities shall be equivalent
abilities of the methods described in this
on when used under more general conditions.
on the quality assurance or quality control
uirements of the referencing Code Section,
ial procedures shall be submitted to the
or acceptance where required, and shall be
part of the Manufacturer's quality control

n an examination to the requirements of this
the Code is required by other Sections of the
Code, it shall be the responsibility of the Manufacturer, fabricator, or installer to establish nondestructive examination procedures and personnel certification procedures conforming to the referencing Code requirements.

(c) When required by the referencing Code Section, all nondestructive examinations performed under this Code Section shall be done to a written procedure. This procedure shall be demonstrated to the satisfaction of the Inspector. The procedure or method shall comply with the applicable requirements of this Section for the particular examination method. Where so required, written procedures shall be made available to the Inspector on request. At least one copy of each procedure shall be readily available to the Manufacturer's Nondestructive Examination Personnel for their reference and use.

T-160 CALIBRATION

(a) The Manufacturer, fabricator, or installer shall assure that all equipment calibrations required by Subsection A and/or Subsection B are performed.

(b) When special procedures are developed [see T-150(a)], the Manufacturer, fabricator, or installer shall specify what calibration is necessary, when calibration is required.

T-170 EXAMINATIONS AND INSPECTIONS

(a) The Inspector concerned with the fabrication of the vessel or pressure part shall have the duty of verifying to his satisfaction that all examinations required by the referencing Code Section have been made to the requirements of this Section and the referencing Code Section. He shall have the right to witness any of these examinations to the extent stated in the referencing Code Section. Throughout this Section of the Code, the word *Inspector* means the *Authorized Inspector* who has been qualified as required in the various referencing Code Sections.

(b) The special distinction established in the various Code Sections between *inspection* and *examination* and the personnel performing them is also adopted in this Code Section. In other words, the term *inspection* applies to the functions performed by the *Authorized Inspector*, but the term *examination* applies to those quality control functions performed by personnel employed by the Manufacturer. One area of occasional deviation from these distinctions exists. In the ASTM Standard Methods and Recommended Practices incorpo-

rated in this Section of the Code by reference or by reproduction in Subsection B, the words *inspection* or *Inspector*, which frequently occur in the text or titles of the referenced ASTM documents, may actually describe what the Code calls *examination* or *examiner*. This situation exists because ASTM has no occasion to be concerned with the distinctions which the Code makes between *inspection* and *examination*, since ASTM activities and documents do not involve the *Authorized Inspector* described in the Code Sections. However, no attempt has been made to edit the ASTM documents to conform with Code usage; this should cause no difficulty if the users of this Section recognize that the terms *inspection, testing,* and *examination* in the ASTM documents referenced in Subsection B do not describe duties of the *Authorized Code Inspector* but rather describe the things to be done by the Manufacturer's *examination* personnel.

T-180 EVALUATION

The acceptance standards for these methods shall be as stated in the referencing Code Section.

T-190 RECORDS/DOCUMENTATION

Records/Documentation shall be in accordance with the referencing Code Section and the applicable requirements of Subsection A and/or B of this Code Section. The Manufacturer, fabricator, or installer shall be responsible for all required Records/Documentation.

ARTICLE 1
MANDATORY APPENDIX

APPENDIX I — GLOSSARY OF TERMS FOR NONDESTRUCTIVE EXAMINATION

I-110 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definition of terms common to all methods used in Nondestructive Examination.

I-120 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 Section A provides the definition of terms listed in I-130(a).

(c) Paragraph I-130(b) provides a list of terms and definitions, which are in addition to SE-1316 and are Code specific.

I-130 REQUIREMENTS

(a) The following SE-1316 terms are used in conjunction with this Article: *defect, discontinuity, evaluation, false indication, flaw, flaw characterization, imperfection, interpretation, nonrelevant indication, relevant indication.*

(b) The following Code terms are used in conjunction with this Article:

area of interest — the specific portion of the object that is to be evaluated as defined by the referencing Code Section

indication — the response or evidence from a nondestructive examination that requires interpretation to determine relevance

inspection — the observation of any operation performed on materials and/or components to determine its acceptability in accordance with given criteria

limited certification — an accreditation of an individual's qualification to perform some but not all of the operations within a given nondestructive examination method or technique that consists of one or more than one operation, or to perform nondestructive examinations within a limited scope of responsibility

method — the following is a list of nondestructive examination methods and respective abbreviations used within the scope of Section V:

RT — Radiography
UT — Ultrasonics
MT — Magnetic Particle
PT — Liquid Penetrants
VT — Visual
LT — Leak Testing
ET — Electromagnetic (Eddy Current)
AE — Acoustic Emission

nondestructive examination (NDE) — the development and application of technical methods to examine materials and/or components in ways that do not impair future usefulness and serviceability in order to detect, locate, measure, interpret, and evaluate flaws

operation — a specific phase of a method or technique

procedure — an orderly sequence of actions describing how a specific technique shall be applied

sensitivity — a measure of the level of response from a discontinuity by a nondestructive examination

technique — a technique is a specific way of utilizing a particular nondestructive examination (NDE) method

01

ARTICLE 2

Figure

Tables

Mandatory Appendices

Figures

Nonmandatory Appendices

Figures

A2.6.1 *Apparatus:*

A2.6.1.1 *Silver Billet Electrode.*

A2.6.1.2 *Glass Electrode,* pH measurement type.

A2.6.1.3 *Buret,* 25-mL capacity, 0.05-mL graduations.

A2.6.1.4 *Millivolt Meter,* or expanded scale pH meter capable of measuring 0 to 220 mV.

Note A2.7 — An automatic titrator is highly recommended in place of items A2.6.1.3 through A2.6.1.4. Repeatability and sensitivity of the method are much enhanced by the automatic equipment while much tedious effort is avoided.

A2.6.2 *Reagents and Materials:*

A2.6.2.1 *Acetone,* chlorine-free.

A2.6.2.2 *Methanol,* chlorine-free.

A2.6.2.3 *Silver Nitrate Solution (0.0282 N)* — Dissolve 4.7910 ± 0.0005 g of silver nitrate ($AgNO_3$) in water and dilute to 1 L.

A2.6.2.4 *Sodium Chloride Solution (0.0282 N)* — Dry a few grams of sodium chloride (NaCl) for 2 h at 130 to 150°C, weigh out 1.6480 ± 0.0005 g of the dried NaCl, dissolve in water, and dilute to 1 L.

A2.6.2.5 *Sulfuric Acid (1 + 2)* — Mix 1 volume of concentrated sulfuric acid (H_2SO_4, sp. gr 1.84) with 2 volumes of water.

A2.6.3 *Collection of Chlorine Solution* — Remove the sample cup with clean forceps and place in a 400-mL beaker. Wash down the walls of the bomb shell with a fine stream of methanol from a wash bottle, and pour the washings into the beaker. Rinse any residue into the beaker. Next, rinse the bomb cover and terminals into the beaker. Finally, rinse both inside and outside of the sample crucible into the beaker. Washings should equal but not exceed 100 mL. Add methanol to make 100 mL.

A2.6.4 *Determination of Chlorine* — Add 5 mL of H_2SO_4 (1:2) to acidify the solution (solution should be acid to litmus and clear of white Na_2CO_3 precipitate). Add 100 mL of acetone. Place the electrodes in the solution, start the stirrer (if mechanical stirrer is to be used), and begin titration. If titration is manual, set the pH meter on the expanded millivolt scale and note the reading. Add exactly 0.1 mL of $AgNO_3$ solution from the buret. Allow a few seconds stirring; then record the new millivolt reading. Subtract the second reading from the first. Continue the titration, noting each amount of $AgNO_3$ solution and the amount of difference between the present reading and the last reading. Continue adding 0.1-mL increments, making readings and determining differences between readings until a maximum difference between readings is obtained. The total amount of $AgNO_3$ solution required to produce this maximum differential is the end point. Automatic titrators continuously stir the sample, add titrant, measure the potential difference, calculate the differential, and plot the differential on a chart. The maximum differential is taken at the end point.

NOTE A2.8 — For maximum sensitivity, 0.00282 *N* $AgNO_3$ solution may be used with the automatic titrator. This dilute reagent should not be used with large samples or where chlorine content may be over 0.1% since these tests will cause end points of 10 mL or higher. The large amount of water used in such titrations reduces the differential between readings, making the end point very difficult to detect. For chlorine contents over 1% in samples of 0.8 g or larger, 0.282 *N* $AgNO_3$ solution will be required to avoid exceeding the 10-mL water dilution limit.

A2.6.5 *Blank* — Make blank determinations with the amount of white oil used but omitting the sample. (Liquid samples normally require only 0.15 to 0.25 g of white oil while solids require 0.7 to 0.8 g.) Follow normal procedure, making two or three test runs to be sure the results are within the limits of repeatability for the test. Repeat this blank procedure whenever new batches of reagents or white oil are used. The purpose of the blank run is to measure the chlorine in the white oil, the reagents, and that introduced by contamination.

A2.6.6 *Standardization* — Silver nitrate solutions are not permanently stable, so the true activity should be checked when the solution is first made up and then periodically during the life of the solution. This is done by titration of a known NaCl solution as follows: Prepare a mixture of the amounts of the chemicals (Na_2CO_3 solution, H_2SO_4 solution, acetone, and methanol) specified for the test. Pipet in 5.0 mL of 0.0282-*N* NaCl solution and titrate to the end point. Prepare and titrate a similar mixture of all the chemicals except the NaCl solution, thus obtaining a reagent blank reading. Calculate the normality of the $AgNO_3$ solution as follows:

$$N_{AgNO_3} = \frac{5.0 \times N_{NaCl}}{V_A - V_B}$$

where:

N_{AgNO_3} = normality of the $AgNO_3$ solution,

N_{NaCl} = normality of the NaCl solution,

V_A = millilitres of $AgNO_3$ solution used for the titration including the NaCl solution, and

T-226 Extent of Examination

The extent of radiographic examination shall be as specified by the referencing Code Section.

T-230 EQUIPMENT AND MATERIALS

T-231 Film

T-231.1 Selection. Film selection shall be in accordance with SE-1815, Standard Test Method for Film Systems for Industrial Radiography. The film manufacturer shall determine the film system class for the family of films manufactured and provide a classification table. A typical Film Classification Table is as shown in SE-1815, Table 1. Film system classes Special, I, II, III, W-A, and W-B are permitted.

Caution — If any of the film processing parameters are changed from those provided by the film manufacturer, the class may not be valid, in which case the film manufacturer should be contacted for further guidance.

T-231.2 Processing. Standard Guide for Controlling the Quality of Industrial Radiographic Film Processing, SE-999, or Part III of Standard Guide for Radiographic Testing SE-94 shall be used as a guide for processing film.

T-232 Intensifying Screens

Intensifying screens may be used when performing radiographic examination in accordance with this Article.

T-233 Image Quality Indicator (IQI) Design

IQIs shall be either the hole type or the wire type. Hole-type IQIs shall be manufactured and identified in accordance with the requirements or alternates allowed in SE-1025. Wire-type IQIs shall be manufactured and identified in accordance with the requirements or alternates allowed in SE-747, except that the largest wire number or the identity number may be omitted. ASME standard IQIs shall consist of those in Table T-233.1 for hole type and those in Table T-233.2 for wire type.

TABLE T-233.1
HOLE-TYPE IQI DESIGNATION, THICKNESS, AND HOLE DIAMETERS

IQI Designation, in. (mm)	IQI Thickness, in. (mm)	1*T* Hole Diameter, in. (mm)	2*T* Hole Diameter, in. (mm)	4*T* Hole Diameter, in. (mm)
5	0.005 (0.13)	0.010 (0.25)	0.020 (0.51)	0.040 (1.02)
7	0.0075 (0.19)	0.010 (0.25)	0.020 (0.51)	0.040 (1.02)
10	0.010 (0.25)	0.010 (0.25)	0.020 (0.51)	0.040 (1.02)
12	0.0125 (0.32)	0.0125 (0.32)	0.025 (0.64)	0.050 (1.27)
15	0.015 (0.38)	0.015 (0.38)	0.030 (0.76)	0.060 (1.52)
17	0.0175 (0.44)	0.0175 (0.44)	0.035 (0.89)	0.070 (1.78)
20	0.020 (0.51)	0.020 (0.51)	0.040 (1.02)	0.080 (2.03)
25	0.025 (0.64)	0.025 (0.64)	0.050 (1.27)	0.100 (2.54)
30	0.030 (0.76)	0.030 (0.76)	0.060 (1.52)	0.120 (3.05)
35	0.035 (0.89)	0.035 (0.89)	0.070 (1.78)	0.140 (3.56)
40	0.040 (1.02)	0.040 (1.02)	0.080 ((2.03)	0.160 (4.06)
45	0.045 (1.14)	0.045 (1.14)	0.090 (2.29)	0.180 (4.57)
50	0.050 (1.27)	0.050 (1.27)	0.100 (2.54)	0.200 (5.08)
60	0.060 (1.52)	0.060 (1.52)	0.120 (3.05)	0.240 (6.10)
70	0.070 (1.78)	0.070 (1.78)	0.140 (3.56)	0.280 (7.11)
80	0.080 (2.03)	0.080 (2.03)	0.160 (4.06)	0.320 (8.13)
100	0.100 (2.54)	0.100 (2.54)	0.200 (5.08)	0.400 (10.16)
120	0.120 (3.05)	0.120 (3.05)	0.240 (6.10)	0.480 (12.19)
140	0.140 (3.56)	0.140 (3.56)	0.280 (7.11)	0.560 (14.22)
160	0.160 (4.06)	0.160 (4.06)	0.320 (8.13)	0.640 (16.26)
200	0.200 (5.08)	0.200 (5.08)	0.400 (10.16)	...
240	0.240 (6.10)	0.240 (6.10)	0.480 (12.19)	...
280	0.280 (7.11)	0.280 (7.11)	0.560 (14.22)	...

TABLE T-233.2
WIRE IQI DESIGNATION, WIRE DIAMETER, AND WIRE IDENTITY

Set A			Set B		
Wire Diameter, in.	(mm)	Wire Identity	Wire Diameter, in.	(mm)	Wire Identity
0.0032	(0.08)	1	0.010	(0.25)	6
0.004	(0.01)	2	0.013	(0.33)	7
0.005	(0.13)	3	0.016	(0.41)	8
0.0063	(0.16)	4	0.020	(0.51)	9
0.008	(0.20)	5	0.025	(0.64)	10
0.010	(0.25)	6	0.032	(0.81)	11
Set C			**Set D**		
Wire Diameter, in.	(mm)	Wire Identit y	Wire Diameter, in.	(mm)	Wire Identit y
0.032	(0.81)	11	0.100	(2.54)	16
0.040	(1.02)	12	0.126	(3.20)	17
0.050	(1.27)	13	0.160	(4.06)	18
0.063	(1.60)	14	0.200	(5.08)	19
0.080	(2.03)	15	0.250	(6.35)	20
0.100	(2.54)	16	0.320	(8.13)	21

T-234 Facilities for Viewing of Radiographs

Viewing facilities shall provide subdued background lighting of an intensity that will not cause troublesome reflections, shadows, or glare on the radiograph. Equipment used to view radiographs for interpretation shall provide a variable light source sufficient for the essential IQI hole or designated wire to be visible for the specified density range. The viewing conditions shall be such that light from around the outer edge of the radiograph or coming through low-density portions of the radiograph does not interfere with interpretation.

T-260 CALIBRATION

T-261 Source Size

T-261.1 Verification of Source Size. The equipment manufacturer's or supplier's publications, such as technical manuals, decay curves, or written statements documenting the actual or maximum source size or focal spot, shall be acceptable as source size verification.

T-261.2 Determination of Source Size. When manufacturer's or supplier's publications are not available, source size may be determined as follows:

(a) X-Ray Machines. For X-ray machines operating at 500 kV and less, the focal spot size may be determined by the pinhole method,[1] or in accordance with SE-1165, Standard Test Method for Measurement of Focal Spots of Industrial X-Ray Tubes by Pinhole Imaging.

(b) Iridium-192 Sources. For Iridium-192, the source size may be determined in accordance with SE-1114, Standard Test Method for Determining the Focal Size of Iridium-192 Industrial Radiographic Sources.

T-262 Densitometer and Step Wedge Comparison Film

T-262.1 Densitometers. Densitometers shall be calibrated at least every 90 days during use as follows:

(a) A national standard step tablet or a step wedge calibration film, traceable to a national standard step tablet and having at least 5 steps with neutral densities from at least 1.0 through 4.0, shall be used. The step wedge calibration film shall have been verified within the last year by comparison with a national standard step tablet.

(b) The densitometer manufacturer's step-by-step instructions for the operation of the densitometer shall be followed.

(c) The density steps closest to 1.0, 2.0, 3.0, and 4.0 on the national standard step tablet or step wedge calibration film shall be read.

(d) The densitometer is acceptable if the density readings do not vary by more than ± 0.05 density units from the actual density stated on the national standard step tablet or step wedge calibration film.

T-262.2 Step Wedge Comparison Films. Step wedge comparison films shall be verified prior to first use, unless performed by the manufacturer, as follows:

(a) The density of the steps on a step wedge comparison film shall be verified by a calibrated densitometer.

(b) The step wedge comparison film is acceptable if the density readings do not vary by more than ± 0.1 density units from the density stated on the step wedge comparison film.

T-262.3 Periodic Verification

(a) Densitometers. Periodic cablibration verification checks shall be performed as described in T-262.1 at the beginning of each shift, after 8 hr of continuous use, or after change of apertures, whichever comes first. The densitometer is acceptable if the density

[1] Nondestructive Testing Handbook, Volume I, First Edition, pp. 14.32–14.33, "Measuring Focal-Spot Size." Also, pp. 20–21 of *Radiography in Modern Industry,* Fourth Edition.

readings are within ± 0.05 of the calibration readings determined in T-262.1(c).

(b) Step Wedge Comparison Films. Verification checks shall be performed annually per T-262.2.

T-262.4 Documentation

(a) Densitometer calibration readings required by T-262.1(c) shall be recorded in an appropriate calibration log.

(b) Periodic verification readings required by T-262.3 do not have to be recorded.

T-270 EXAMINATION

T-271 Radiographic Technique[2]

A single-wall exposure technique shall be used for radiography whenever practical. When it is not practical to use a single-wall technique, a double-wall technique shall be used. An adequate number of exposures shall be made to demonstrate that the required coverage has been obtained.

T-271.1 Single-Wall Technique. In the single-wall technique, the radiation passes through only one wall of the weld (material), which is viewed for acceptance on the radiograph.

T-271.2 Double-Wall Technique. When it is not practical to use a single-wall technique, one of the following double-wall techniques shall be used.

(a) Single-Wall Viewing. For materials and for welds in components, a technique may be used in which the radiation passes through two walls and only the weld (material) on the film-side wall is viewed for acceptance on the radiograph. When complete coverage is required for circumferential welds (materials), a minimum of three exposures taken 120 deg. to each other shall be made.

(b) Double-Wall Viewing. For materials and for welds in components $3\frac{1}{2}$ in. (89 mm) or less in nominal outside diameter, a technique may be used in which the radiation passes through two walls and the weld (material) in both walls is viewed for acceptance on the same radiograph. For double-wall viewing, only a source-side IQI shall be used. Care should be exercised to ensure that the required geometric unsharpness is not exceeded. If the geometric unsharpness requirement cannot be met, then single-wall viewing shall be used.

(1) For welds, the radiation beam may be offset from the plane of the weld at an angle sufficient to separate the images of the source-side and film-side portions of the weld so that there is no overlap of the areas to be interpreted. When complete coverage is required, a minimum of two exposures taken 90 deg. to each other shall be made for each joint.

(2) As an alternative, the weld may be radiographed with the radiation beam positioned so that the images of both walls are superimposed. When complete coverage is required, a minimum of three exposures taken at either 60 deg. or 120 deg. to each other shall be made for each joint.

(3) Additional exposures shall be made if the required radiographic coverage cannot be obtained using the minimum number of exposures indicated in (b)(1) or (b)(2) above.

T-272 Radiation Energy 01

The radiation energy employed for any radiographic technique shall achieve the density and IQI image requirements of this Article.

T-273 Direction of Radiation

The direction of the central beam of radiation should be centered on the area of interest whenever practical.

T-274 Geometric Unsharpness

Geometric unsharpness of the radiograph shall be determined in accordance with:

$$Ug = Fd/D$$

where

Ug = geometric unsharpness

F = source size: the maximum projected dimension of the radiating source (or effective focal spot) in the plane perpendicular to the distance D from the weld or object being radiographed, in.

D = distance from source of radiation to weld or object being radiographed, in.

d = distance from source side of weld or object being radiographed to the film

NOTE: Refer to Standard Guide for Radiographic Testing SE-94 for a method of determining geometric unsharpness. Alternatively, a nomograph as shown in Standard Guide for Radiographic Testing SE-94 may be used.

T-275 Location Markers

Location markers (see Fig. T-275), which are to appear as radiographic images on the film, shall be

[2] Sketches showing suggested source, film, and IQI placements for pipe or tube welds are illustrated in Article 2, Nonmandatory Appendix A.

placed on the part, not on the exposure holder/cassette. Their locations shall be permanently marked on the surface of the part being radiographed when permitted, or on a map, in a manner permitting the area of interest on a radiograph to be accurately traceable to its location on the part, for the required retention period of the radiograph. Evidence shall also be provided on the radiograph that the required coverage of the region being examined has been obtained. Location markers shall be placed as follows.

T-275.1 Single-Wall Viewing

(a) Source-Side Markers. Location markers shall be placed on the source side when radiographing the following:

(1) flat components or longitudinal joints in cylindrical or conical components;

(2) curved or spherical components whose concave side is toward the source and when the "source-to-material" distance is less than the inside radius of the component;

(3) curved or spherical components whose convex side is toward the source.

(b) Film-Side Markers

(1) Location markers shall be placed on the film side when radiographing either curved or spherical components whose concave side is toward the source and when the "source-to-material" distance is greater than the inside radius.

(2) As an alternative to source-side placement in T-275.1(a)(1), location markers may be placed on the film side when the radiograph shows coverage beyond the location markers to the extent demonstrated by Fig. T-275, sketch (e), and when this alternate is documented in accordance with T-291.

(c) Either Side Markers. Location markers may be placed on either the source side or film side when radiographing either curved or spherical components whose concave side is toward the source and the "source-to-material" distance equals the inside radius of the component.

T-275.2 Double-Wall Viewing. For double-wall viewing, at least one location marker shall be placed adjacent to the weld (or on the material in the area of interest) for each radiograph.

T-275.3 Mapping the Placement of Location Markers. When inaccessibility or other limitations prevent the placement of markers as stipulated in T-275.1 and T-275.2, a dimensioned map of the actual marker placement shall accompany the radiographs to show that full coverage has been obtained.

T-276 IQI Selection

T-276.1 Material. IQIs shall be selected from either the same alloy material group or grade as identified in SE-1025 or from an alloy material group or grade with less radiation absorption than the material being radiographed.

T-276.2 Size. The designated hole IQI or essential wire shall be as specified in Table T-276. A thinner or thicker hole-type IQI may be substituted for any section thickness listed in Table T-276, provided an equivalent IQI sensitivity is maintained. See T-283.2.

(a) Welds With Reinforcements. The thickness on which the IQI is based is the nominal single-wall thickness plus the estimated weld reinforcement not to exceed the maximum permitted by the referencing Code Section. Backing rings or strips shall not be considered as part of the thickness in IQI selection. The actual measurement of the weld reinforcement is not required.

(b) Welds Without Reinforcements. The thickness on which the IQI is based is the nominal single-wall thickness. Backing rings or strips shall not be considered as part of the weld thickness in IQI selection.

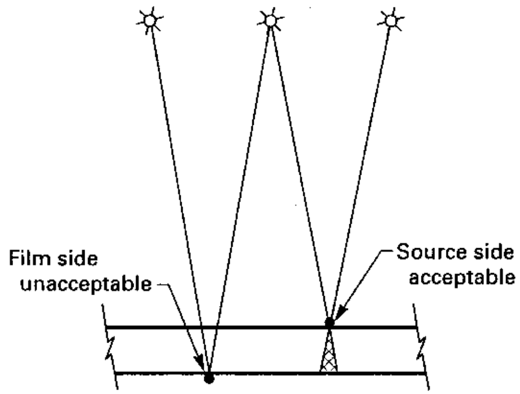
T-276.3 Welds Joining Dissimilar Materials or Welds With Dissimilar Filler Metal. When the weld metal is of an alloy group or grade that has a radiation attenuation that differs from the base material, the IQI material selection shall be based on the weld metal and be in accordance with T-276.1. When the density limits of T-282.2 cannot be met with one IQI, and the exceptional density area(s) is at the interface of the weld metal and the base metal, the material selection for the additional IQIs shall be based on the base material and be in accordance with T-276.1.

T-277 Use of IQIs to Monitor Radiographic Examination

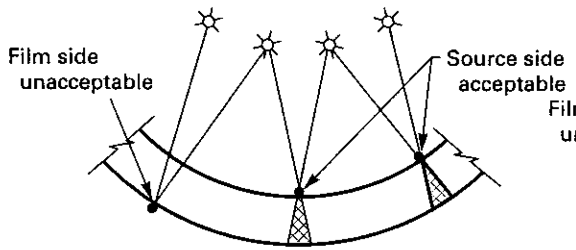
T-277.1 Placement of IQIs

(a) Source-Side IQI(s). The IQI(s) shall be placed on the source side of the part being examined, except for the condition described in T-277.1(b).

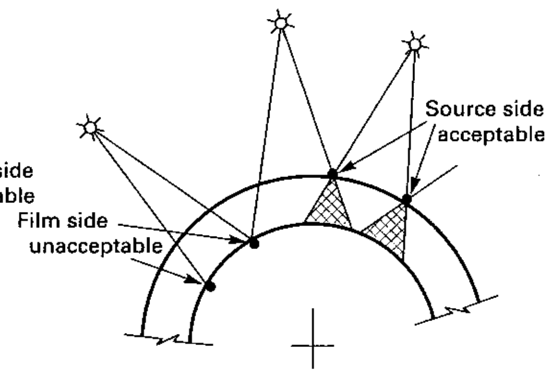
When, due to part or weld configuration or size, it is not practical to place the IQI(s) on the part or weld, the IQI(s) may be placed on a separate block. Separate blocks shall be made of the same or radiographically similar materials (as defined in SE-1025) and may be used to facilitate IQI positioning. There is no restriction on the separate block thickness, provided the IQI/area-of-interest density tolerance requirements of T-282.2 are met.



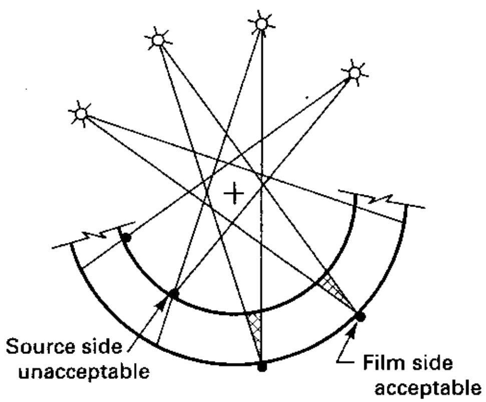
Flat component or longitudinal seam
[See T-275.1(a)(1)]
[See sketch (e) for alternate]
(a)



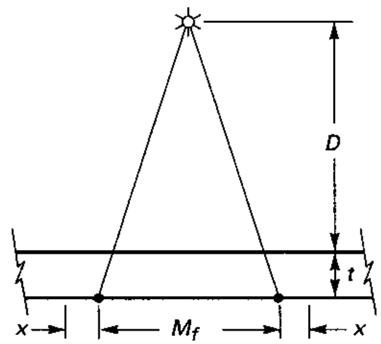
Curved components with radiation source to film distance less than radius of component
[See T-275.1(a)(2)]
(b)



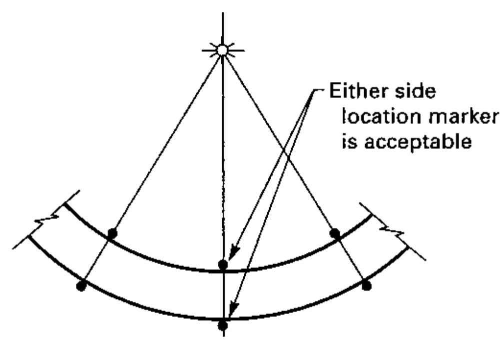
Curved components with convex surface towards radiation source
[See T-275.1(a)(3)]
(c)



Curved components with radiation source to film distance greater than radius of curvature
[See T-275.1(b)(1)]
(d)



Source side marker alternate
Flat component or logitudinal seam
$x = (t / D)\,(M_f / 2)$
x = **additional required coverage beyond film side location marker**
t = **component thickness**
M_f = **film side location marker interval**
D = **source to component distance**
[See T-275.1(b)(2)]
(e)



Curved components with radiation source at center curvature
[See T-275.1(c)]
(f)

LEGEND: Radiation source — ☼
Location marker — •
Component center — +

FIG. T-275 LOCATION MARKER SKETCHES

TABLE T-276
IQI SELECTION

Nominal Single-Wall Material Thickness Range		IQI			
		Source Side		Film Side	
in.	mm	Hole-Type Designation	Wire-Type Essential Wire	Hole-Type Designation	Wire-Type Essential Wire
p to 0.25, incl.	Up to 6.4, incl.	12	5	10	4
ver 0.25 through 0.375	Over 6.4 through 9.5	15	6	12	5
ver 0.375 through 0.50	Over 9.5 through 12.7	17	7	15	6
ver 0.50 through 0.75	Over 12.7 through 19.0	20	8	17	7
ver 0.75 through 1.00	Over 19.0 through 25.4	25	9	20	8
ver 1.00 through 1.50	Over 25.4 through 38.1	30	10	25	9
ver 1.50 through 2.00	Over 38.1 through 50.8	35	11	30	10
ver 2.00 through 2.50	Over 50.8 through 63.5	40	12	35	11
ver 2.50 through 4.00	Over 63.5 through 101.6	50	13	40	12
ver 4.00 through 6.00	Over 101.6 through 152.4	60	14	50	13
ver 6.00 through 8.00	Over 152.4 through 203.2	80	16	60	14
ver 8.00 through 10.00	Over 203.2 through 254.0	100	17	80	16
ver 10.00 through 12.00	Over 254.0 through 304.8	120	18	100	17
ver 12.00 through 16.00	Over 304.8 through 406.4	160	20	120	18
ver 16.00 through 20.00	Over 406.4 through 508.0	200	21	160	20

(1) The IQI on the source side of the separate lock shall be placed no closer to the film than the ource side of the part being radiographed.

(2) The separate block shall be placed as close s possible to the part being radiographed.

(3) The block dimensions shall exceed the IQI imensions such that the outline of at least three sides f the IQI image shall be visible on the radiograph.

(b) Film-Side IQI(s). Where inaccessibility prevents and placing the IQI(s) on the source side, the IQI(s) hall be placed on the film side in contact with the art being examined. A lead letter "F" shall be placed djacent to or on the IQI(s), but shall not mask the ssential hole where hole IQIs are used.

(c) IQI Placement for Welds — Hole IQIs. The QI(s) may be placed adjacent to or on the weld. The lentification number(s) and, when used, the lead letter F," shall not be in the area of interest, except when eometric configuration makes it impractical.

(d) IQI Placement for Welds — Wire IQIs. The QI(s) shall be placed on the weld so that the length f the wires is perpendicular to the length of the weld. 'he identification numbers and, when used, the lead ɜtter "F," shall not be in the area of interest, except /hen geometric configuration makes it impractical.

(e) IQI Placement for Materials Other Than Welds. 'he IQI(s) with the IQI identification number(s), and, when used, the lead letter "F," may be placed in the area of interest.

T-277.2 Number of IQIs. When one or more film holders are used for an exposure, at least one IQI image shall appear on each radiograph except as outlined in (b) below.

(a) Multiple IQIs. If the requirements of T-282 are met by using more than one IQI, one shall be representative of the lightest area of interest and the other the darkest area of interest; the intervening densities on the radiograph shall be considered as having acceptable density.

(b) Special Cases[3]

(1) For cylindrical components where the source is placed on the axis of the component for a single exposure, at least three IQIs, spaced approximately 120 deg. apart, are required under the following conditions:

(a) When the complete circumference is radiographed using one or more film holders, or;

(b) When a section or sections of the circumference, where the length between the ends of the outermost sections span 240 or more deg., is radiographed using one or more film holders. Additional film locations may be required to obtain necessary IQI spacing.

[3] Refer to Nonmandatory Appendix D for additional guidance.

(2) For cylindrical components where the source is placed on the axis of the component for a single exposure, at least three IQIs, with one placed at each end of the span of the circumference radiographed and one in the approximate center of the span, are required under the following conditions:

(a) When a section of the circumference, the length of which is greater than 120 deg. and less than 240 deg., is radiographed using just one film holder, or;

(b) When a section or sections of the circumference, where the length between the ends of the outermost sections span less than 240 deg., is radiographed using more than one film holder.

(3) In *(1)* and *(2)* above, where sections of longitudinal welds adjoining the circumferential weld are radiographed simultaneously with the circumferential weld, an additional IQI shall be placed on each longitudinal weld at the end of the section most remote from the junction with the circumferential weld being radiographed.

(4) For spherical components where the source is placed at the center of the component for a single exposure, at least three IQIs, spaced approximately 120 deg. apart, are required under the following conditions:

(a) When a complete circumference is radiographed using one or more film holders, or;

(b) When a section or sections of a circumference, where the length between the ends of the outermost sections span 240 or more deg., is radiographed using one or more film holders. Additional film locations may be required to obtain necessary IQI spacing.

(5) For spherical components where the source is placed at the center of the component for a single exposure, at least three IQIs, with one placed at each end of the radiographed span of the circumference radiographed and one in the approximate center of the span, are required under the following conditions:

(a) When a section of a circumference, the length of which is greater than 120 deg. and less than 240 deg., is radiographed using just one film holder, or;

(b) When a section or sections of a circumference, where the length between the ends of the outermost sections span less than 240 deg. is radiographed using more than one film holder.

(6) In *(4)* and *(5)* above, where other welds are radiographed simultaneously with the circumferential weld, one additional IQI shall be placed on each other weld.

(7) When an array of components in a circle is radiographed, at least one IQI shall show on each component image.

(8) In order to maintain the continuity of records involving subsequent exposures, all radiographs exhibiting IQIs that qualify the techniques permitted in accordance with *(1)* through *(6)* above shall be retained.

T-277.3 Shims Under Hole IQIs. For welds, a shim of material radiographically similar to the weld metal shall be placed between the part and the IQI, if needed, so that the radiographic density throughout the area of interest is no more than minus 15% from (lighter than) the radiographic density through the IQI.

The shim dimensions shall exceed the IQI dimensions such that the outline of at least three sides of the IQI image shall be visible in the radiograph.

T-280 EVALUATION

T-281 Quality of Radiographs

All radiographs shall be free from mechanical, chemical, or other blemishes to the extent that they do not mask and are not confused with the image of any discontinuity in the area of interest of the object being radiographed. Such blemishes include, but are not limited to:

(a) fogging;

(b) processing defects such as streaks, watermarks, or chemical stains;

(c) scratches, finger marks, crimps, dirtiness, static marks, smudges, or tears;

(d) false indications due to defective screens.

T-282 Radiographic Density

T-282.1 Density Limitations. The transmitted film density through the radiographic image of the body of the appropriate hole IQI or adjacent to the designated wire of a wire IQI and the area of interest shall be 1.8 minimum for single film viewing for radiographs made with an X-ray source and 2.0 minimum for radiographs made with a gamma ray source. For composite viewing of multiple film exposures, each film of the composite set shall have a minimum density of 1.3. The maximum density shall be 4.0 for either single or composite viewing. A tolerance of 0.05 in density is allowed for variations between densitometer readings.

T-282.2 Density Variation

(a) General. If the density of the radiograph anywhere through the area of interest varies by more than minus 15% or plus 30% from the density through the body of the hole IQI or adjacent to the designated wire of a wire IQI, within the minimum/maximum allowable

TABLE T-283
EQUIVALENT HOLE-TYPE IQI SENSITIVITY

Hole-Type Designation 2*T* Hole	Equivalent Hole-Type Designations	
	1*T* Hole	4*T* Hole
10	15	5
12	17	7
15	20	10
17	25	12
20	30	15
25	35	17
30	40	20
35	50	25
40	60	30
50	70	35
60	80	40
80	120	60
100	140	70
120	160	80
160	240	120
200	280	140

density ranges specified in T-282.1, then an additional IQI shall be used for each exceptional area or areas and the radiograph retaken. When calculating the allowable variation in density, the calculation may be rounded to the nearest 0.1 within the range specified in T-282.1.

(b) With Shims. When shims are used the plus 30% density restriction of (a) above may be exceeded, provided the required IQI sensitivity is displayed and the density limitations of T-282.1 are not exceeded.

T-283 IQI Sensitivity

T-283.1 Required Sensitivity. Radiography shall be performed with a technique of sufficient sensitivity to display the designated hole IQI image and the 2*T* hole, or the essential wire of a wire IQI. The radiographs shall also display the IQI identifying numbers and letters. If the designated hole IQI image and 2*T* hole, or essential wire, do not show on any film in a multiple film technique, but do show in composite film viewing, interpretation shall be permitted only by composite film viewing.

T-283.2 Equivalent Hole-Type Sensitivity. If a thinner or thicker hole-type IQI than listed in Table T-276 was substituted, an equivalent IQI sensitivity, as specified in Table T-283, shall have been maintained as well as all other requirements for radiography having been met.

T-284 Excessive Backscatter

If a light image of the "B," as described in T-223, appears on a darker background of the radiograph, protection from backscatter is insufficient and the radiograph shall be considered unacceptable. A dark image of the "B" on a lighter background is not cause for rejection.

T-285 Geometric Unsharpness Limitations 01

Geometric unsharpness of the radiograph shall not exceed the following:

Material Thickness, in. (mm)	*Ug* Maximum, in. (mm)
Under 2 (50.8)	0.020 (0.51)
2 through 3 (50.8–76.2)	0.030 (0.76)
Over 3 through 4 (76.2–101.6)	0.040 (1.02)
Greater than 4 (101.6)	0.070 (1.78)

NOTE: Material thickness is the thickness on which the IQI is based.

T-286 Evaluation by Manufacturer 01

The Manufacturer shall be responsible for the review, interpretation, evaluation, and acceptance of the completed radiographs to assure compliance with the requirements of Article 2 and the referencing Code Section. As an aid to the review and evaluation, the radiographic technique documentation required by T-291 shall be completed prior to the evaluation. The radiograph review form required by T-292 shall be completed during the evaluation. The radiographic technique details and the radiograph review form documentation shall accompany the radiographs. Acceptance shall be completed prior to presentation of the radiographs and accompanying documentation to the Inspector.

T-290 DOCUMENTATION

T-291 Radiographic Technique Documentation Details

The Manufacturer shall prepare and document the radiographic technique details. As a minumum, the following information shall be provided.

(a) identification, e.g., job/contract number and heat number (if applicable)

(b) the dimensional map (if used) of marker placement in accordance with T-275.3

(c) number of radiographs (exposures)

(d) X-ray voltage or isotope type used

(e) X-ray machine focal spot size or isotope physical sources size

(f) base material type and thickness, weld thickness, weld reinforcement thickness, as applicable

(g) minimum source-to-object distance

(h) maximum distance from source side of object to the film

(i) film manufacturer and Manufacturer's type/designation

(j) number of film in each film holder/cassette

(k) single- or double-wall exposure

(l) single- or double-wall viewing

T-292 Radiograph Review Form

The Manufacturer shall prepare a radiograph review form. As a minimum, the following information shall be provided.

(a) a listing of each radiograph location

(b) the information required in T-291, by inclusion or by reference

(c) evaluation and disposition of the material(s) or weld(s) examined

(d) identification (name) of the Manufacturer's representative who performed the final acceptance of the radiographs

(e) date of Manufacturer's evaluation

ARTICLE 2
MANDATORY APPENDIX

APPENDIX I — IN-MOTION RADIOGRAPHY

I-210 SCOPE

In-motion radiography is a technique of radiography where the object being radiographed and/or the source of radiation is in motion during the exposure.

In-motion radiography may be performed on weldments when the following modified provisions to those in Article 2 are satisfied.

I-220 GENERAL REQUIREMENTS

I-223 Backscatter Detection Symbol Location

(a) For longitudinal welds the lead symbol "B" shall be attached to the back of each film cassette or at approximately equal intervals not exceeding 36 in. (914 mm) apart, whichever is smaller.

(b) For circumferential welds, the lead symbol "B" shall be attached to the back of the film cassette in each quadrant or spaced no greater than 36 in. (914 mm), whichever is smaller.

I-260 CALIBRATION

I-263 Beam Width

The beam width shall be controlled by a metal diaphragm such as lead. The diaphragm for the energy selected shall be at least 10 half value layers thick.

The beam width as shown in Fig. I-263 shall be determined in accordance with:

$$w = \frac{c\,(F + a)}{b} + a$$

where

w = beam width at the source side of the weld measured in the direction of motion
a = slit width in diaphragm in direction of motion
b = distance from source to the weld side of the diaphragm
c = distance from weld side of the diaphragm to the source side of the weld surface
F = source size: the maximum projected dimension of the radiating source (or focal spot) in the plane perpendicular to the distance $b + c$ from the weld being radiographed

NOTE: Use consistent units.

I-270 EXAMINATION

I-274 Geometric and In-Motion Unsharpness

I-274.1 Geometric Unsharpness. Geometric unsharpness for an in-motion radiograph shall be determined as specified in T-274.

I-274.2 In-Motion Unsharpness. In-motion unsharpness of the radiograph shall be determined in accordance with:

$$U_M = \frac{wd}{D}$$

where

U_M = in-motion unsharpness
w = beam width at the source side of the weld measured in the direction of motion determined as specified in I-263
d = distance from source side of the weld being radiographed to the film
D = distance from source of radiation to weld being radiographed

NOTE: Use consistent units

I-275 Location Markers

Location markers shall be placed adjacent to the weld at the extremity of each film cassette and

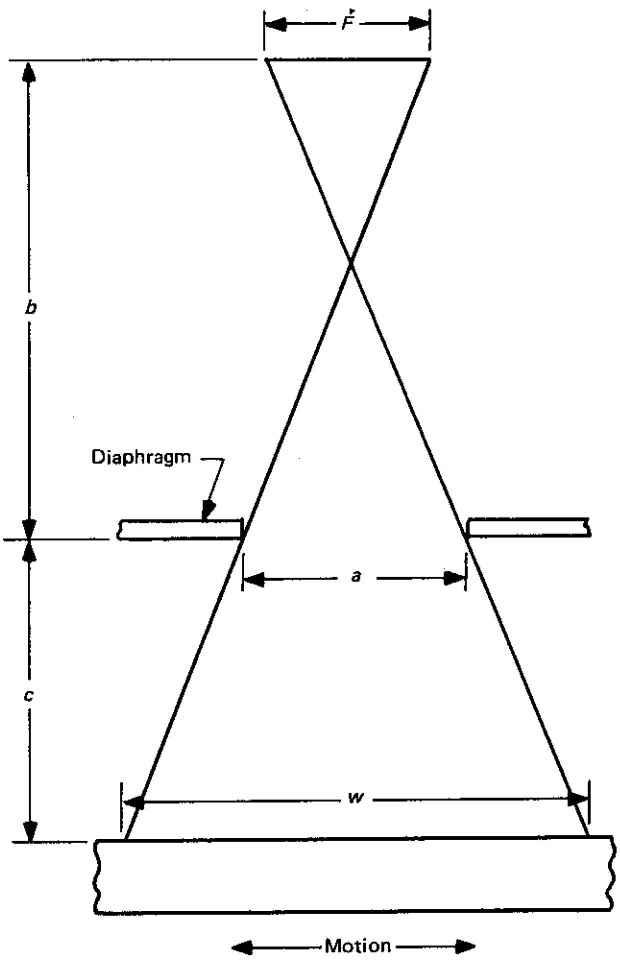


FIG. I-263

also at approximately equal intervals not exceeding 15 in. (381 mm).

I-277 Placement and Number of IQIs

(a) For longitudinal welds, hole IQIs shall be placed adjacent to and on each side of the weld seam, or on the weld seam at the beginning and end of the weld seam, and thereafter at approximately equal intervals not exceeding 36 in. (914 mm) or for each film cassette. Wire IQIs, when used, shall be placed on the weld seam so that the length of the wires is perpendicular to the length of the weld and spaced as indicated above for hole IQIs.

(b) For circumferential welds, hole IQIs shall be placed adjacent to and on each side of the weld seam or on the weld seam in each quadrant or spaced no greater than 36 in. (914 mm) apart, whichever is smaller. Wire IQIs, when used, shall be placed on the weld seam so that the length of the wires is perpendicular to the length of the weld and spaced as indicated above for hole IQIs.

I-279 Repaired Area

When radiography of a repaired area is required, the length of the film used shall be at least equal to the length of the original location marker interval.

I-280 EVALUATION

I-285 Geometric and In-Motion Unsharpness Limitations

Neither the geometric nor in-motion unsharpness of the radiograph shall exceed the values specified in T-285.

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APPENDIX II — REAL-TIME RADIOSCOPIC EXAMINATION

II-210 SCOPE

Real-time radioscopy provides immediate response imaging with the capability to follow motion of the inspected part. This includes radioscopy where the motion of the test object must be limited (commonly referred to as near real-time radioscopy).

Real-time radioscopy may be performed on materials including castings and weldments when the modified provisions to Article 2 as indicated herein are satisfied. SE-1255 shall be used in conjunction with this Appendix as indicated by specific references in appropriate paragraphs. SE-1416 provides additional information that may be used for radioscopic examination of welds.

II-220 GENERAL REQUIREMENTS

This radioscopic methodology may be used for the examination of ferrous or nonferrous materials and weldments.

II-221 Procedure Requirements

A written procedure is required and shall contain as a minimum the following (see SE-1255, 5.2):

(a) material and thickness range
(b) equipment qualifications
(c) test object scan plan
(d) radioscopic parameters
(e) image processing parameters
(f) image display parameters
(g) image archiving

II-230 EQUIPMENT AND MATERIALS

II-231 Radioscopic Examination Record

The radioscopic examination data shall be recorded and stored on videotape, magnetic disk, or optical disk.

II-235 Calibration Block

The calibration block shall be made of the same material type and product form as the test object. The calibration block may be an actual test object or may be fabricated to simulate the test object with known discontinuities.

II-236 Calibrated Line Pair Test Pattern and Step Wedge

The line pair test pattern shall be used without an additional absorber to evaluate the system resolution. The step wedge shall be used to evaluate system contrast sensitivity.

The step wedge must be made of the same material as the test object with steps representing 100%, 99%, 98%, and 97% of both the thickest and the thinnest material sections to be inspected. Additional step thicknesses are permissible.

II-237 Equivalent Performance Level

A system which exhibits a spatial resolution of 3 line pairs per millimeter, a thin section contrast sensitivity of 3%, and a thick section contrast sensitivity of 2% has an equivalent performance level of 3% — 2% — 3 lp/mm.

II-260 CALIBRATION

System calibration shall be performed in the static mode by satisfying the line pair test pattern resolution, step wedge contrast sensitivity, and calibration block discontinuity detection necessary to meet the IQI requirements of T-276.

II-263 System Performance Measurement

Real-time radioscopic system performance parameters shall be determined initially and monitored regularly with the system in operation to assure consistent results.

The system performance shall be monitored at sufficiently scheduled intervals to minimize the probability of time-dependent performance variations. System performance tests require the use of the calibration block, line pair test pattern, and the step wedge.

System performance measurement techniques shall be standardized so that they may be readily duplicated at the specified intervals.

II-264 Measurement With a Calibration Block

The calibration block shall also be placed in the same position as the actual object and manipulated through the same range and speed of motions as will be used for the actual object to demonstrate the system's response in the dynamic mode.

II-270 EXAMINATION

II-278 System Configuration

The radioscopic examination system shall, as a minimum, include the following:

(a) radiation source
(b) manipulation system
(c) detection system
(d) information processing system
(e) image display system
(f) record archiving system

II-280 EVALUATION

II-286 Factors Affecting System Performance

The radioscopic examination system performance quality is determined by the combined performance of the components specified in II-278. (See SE-1255, 6.1.)

When using wire IQIs, the radioscopic examination system may exhibit asymmetrical sensitivity, therefore, the wire diameter axis shall be oriented along the axis of the least sensitivity of the system.

II-290 DOCUMENTATION

II-291 Radioscopic Technique Information

To aid in proper interpretation of the radioscopic examination data, details of the technique used shall accompany the data. As a minimum, the information shall include the items specified in T-291 when applicable, II-221, and the following:

(a) operator identification
(b) system performance test data

II-292 Evaluation by Manufacturer

Prior to being presented to the Inspector for acceptance, the examination data shall be interpreted by the Manufacturer as complying with the referencing Code Section. The Manufacturer shall record the interpretation and disposition of each weldment examined on a radiographic interpretation review form accompanying the radioscopic data.

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APPENDIX III — DIGITAL IMAGE ACQUISITION, DISPLAY, AND STORAGE FOR RADIOGRAPHY AND RADIOSCOPY

III-210 SCOPE

Digital image acquisition, display, and storage can be applied to radiography and radioscopy. Once the analog image is converted to digital format, the data can be displayed, processed, quantified, stored, retrieved, and converted back to the original analog format, for example, film or video presentation.

Digital imaging of all radiographic and radioscopic examination test results shall be performed in accordance with the modified provisions to Article 2 as indicated herein.

III-220 GENERAL REQUIREMENTS

III-221 Procedure Requirements

A written procedure is required and shall contain, as a minimum, the following system performance parameters:

(a) image digitizing parameters — modulation transfer function (MTF), line pair resolution, contrast sensitivity, and dynamic range;

(b) image display parameters — format, contrast, and magnification;

(c) image processing parameters that are used;

(d) storage — identification, data compression, and media (including precautions to be taken to avoid data loss);

(e) analog output formats.

III-222 Original Image Artifacts

Any artifacts that are identified in the original image shall be noted or annotated on the digital image.

III-230 EQUIPMENT AND MATERIALS

III-231 Digital Image Examination Record

The digital image examination data shall be recorded and stored on video tape, magnetic disk, or optical disk.

III-234 Viewing Considerations

The digital image shall be judged by visual comparison to be equivalent to the image quality of the original image at the time of digitization.

III-236 Calibrated Optical Line Pair Test Pattern and Optical Density Step Wedge

An optical line pair test pattern operating between 0.1 and 4.0 optical density shall be used to evaluate the modulation transfer function (MTF) of the system. The optical density step wedge shall be used to evaluate system contrast sensitivity.

III-250 IMAGE ACQUISITION AND STORAGE

III-255 Area of Interest

Any portion of the image data may be digitized and stored provided the information that is digitized and stored includes the area of interest as defined by the referencing Code Section.

III-258 System Configuration

The system shall, as a minimum, include the following:

(a) digitizing system

(b) display system

(c) image processing system

(d) image storage system

III-260 CALIBRATION

The system shall be calibrated for modulation transfer function (MTF), dynamic range, and contrast sensitivity.

III-263 System Performance Measurement

System performance parameters (as noted in III-221) shall be determined initially and monitored regularly with the system in operation to assure consistent results. The system performance shall be monitored at the beginning and end of each shift to minimize the probability of time-dependent performance variations.

III-280 EVALUATION

III-286 Factors Affecting System Performance

The quality of system performance is determined by the combined performance of the components specified in III-258.

III-287 System-Induced Artifacts

The digital images shall be free of system-induced artifacts in the area of interest that could mask or be confused with the image of any discontinuity in the original analog image.

III-290 DOCUMENTATION

III-291 Digital Imaging Technique Information

To aid in proper interpretation of the digital examination data, details of the technique used shall accompany the data. As a minimum, the information shall include items specified in T-291 and II-221 when applicable, III-221, III-222, and the following:

(a) operator identification

(b) system performance test data

III-292 Evaluation by Manufacturer

Prior to being presented to the Inspector for acceptance, the digital examination data from a radiographic or radioscopic image shall have been interpreted by the Manufacturer as complying with the referencing Code Section.

The digital examination data from a radiograph that has previously been accepted by the Inspector is not required to be submitted to the Inspector for acceptance.

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MANDATORY APPENDIX

APPENDIX IV — INTERPRETATION, EVALUATION, AND DISPOSITION OF RADIOGRAPHIC AND RADIOSCOPIC EXAMINATION TEST RESULTS PRODUCED BY THE DIGITAL IMAGE ACQUISITION AND DISPLAY PROCESS

IV-210 SCOPE

The digital image examination test results produced in accordance with Article 2, Mandatory Appendix II, and Article 2, Mandatory Appendix III, may be interpreted and evaluated for final disposition in accordance with the additional provisions to Article 2 as indicated herein.

The digital information is obtained in series with radiography and in parallel with radioscopy. This data collection process also provides for interpretation, evaluation, and disposition of the examination test results.

IV-220 GENERAL REQUIREMENTS

The digital image shall be interpreted while displayed on a cathode ray tube (soft display). The interpretation may include density and contrast adjustment, quantification, and pixel measurement, including digital or optical density values and linear or area measurement.

The interpretation of a digitized image is dependent upon the same subjective evaluation by a trained interpreter as the interpretation of a radiographic or radioscopic image. Some of the significant parameters considered during interpretation include: area of interest, image quality, IQI image, magnification, density, contrast, discontinuity shape (rounded, linear, irregular), and artifact identification.

The digital image interpretation of the radiographic and radioscopic examination test results shall be performed in accordance with the modified provisions to Article 2 as indicated herein.

After the interpretation has been completed, the interpretation data and the digital image, which shall include the unprocessed original full image and the digitally processed image, shall be recorded and stored on video tape, magnetic tape, or optical disk.

IV-221 Procedure Requirements

A written procedure is required and shall contain, as a minimum, the following system performance parameters:

(a) image digitizing parameters — modulation transfer function (MTF), line pair resolution, contrast sensitivity, dynamic range, and pixel size;

(b) image display parameters — monitor size including display pixel size, luminosity, format, contrast, and magnification;

(c) signal processing parameters — including density shift, contrast stretch, log transform, and any other techniques that do not mathematically alter the original digital data, e.g., linear and area measurement, pixel sizing, and value determination;

(d) storage — identification, data compression, and media (including precautions to be taken to avoid data loss). The non-erasable optical media should be used for archival applications. This is frequently called the WORM (Write Once Read Many) technology. When storage is accomplished on magnetic or erasable optical media, then procedures must be included that show trackable safeguards to prevent data tampering and guarantee data integrity.

IV-222 Original Image Artifacts

Any artifacts that are identified shall be noted or annotated on the digital image.

IV-230 EQUIPMENT AND MATERIALS

IV-231 Digital Image Examination Record

The digital image examination data shall be recorded and stored on video tape, magnetic disk, or optical disk.

IV-234 Viewing Considerations

The digital image shall be evaluated using appropriate monitor luminosity, display techniques, and room lighting to insure proper visualization of detail.

IV-236 Calibrated Optical Line Pair Test Pattern and Optical Density Step Wedge

An optical line pair test pattern operating between 0.1 and 4.0 optical density shall be used to evaluate the modulation transfer function (MTF) of the system. High spatial resolution with 14 line-pairs per millimeter (lp/mm) translates to a pixel size of 0.0014 in. (0.035 mm). Lesser spatial resolution with 2 lp/mm can be accomplished with a pixel size of 0.012 in. (0.3 mm). The optical density step wedge shall be used to evaluate system contrast sensitivity. Alternatively, a contrast sensitivity gage (step wedge block) in accordance with SE-1647 may be used.

IV-250 IMAGE ACQUISITION, STORAGE, AND INTERPRETATION

IV-255 Area of Interest

The evaluation of the digital image shall include all areas of the image defined as the area of interest by the referencing Code Section.

IV-258 System Configuration

The system shall, as a minimum, include:

(a) digital image acquisition system

(b) display system

(c) image processing system

(d) image storage system

IV-260 CALIBRATION

The system shall be calibrated for modulation transfer function (MTF), dynamic range, and contrast sensitivity. The electrical performance of the hardware and the quality of the digital image shall be measured and recorded.

IV-263 System Performance Measurement

System performance parameters (as noted in IV-221) shall be determined initially and monitored regularly with the system in operation to assure consistent results. The system performance shall be monitored at the beginning and end of each shift to minimize the probability of time-dependent performance variations.

IV-280 EVALUATION

IV-286 Factors Affecting System Performance

The quality of system performance is determined by the combined performance of the components specified in IV-258.

IV-287 System-Induced Artifacts

The digital images shall be free of system-induced artifacts in the area of interest that could mask or be confused with the image of any discontinuity.

IV-290 DOCUMENTATION

IV-291 Digital Imaging Technique Information

To aid in proper interpretation of the digital examination data, details of the technique used shall accompany the data. As a minimum, the information shall include items specified in T-291 and II-221 when applicable, III-221, III-222, IV-221, IV-222, and the following:

(a) operator identification

(b) system performance test data

(c) calibration test data

IV-292 Evaluation by Manufacturer

Prior to being presented to the Inspector for acceptance, the digital examination data from a radiographic or radioscopic image shall have been interpreted by the Manufacturer as complying with the referencing Code Section.

The digitized examination data that has previously been accepted by the Inspector is not required to be submitted to the Inspector for acceptance.

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MANDATORY APPENDIX

APPENDIX V — GLOSSARY OF TERMS FOR RADIOGRAPHIC EXAMINATION

V-210 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms relating to radiographic examination.

V-220 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 Section 7 provides the definitions of terms listed in V-230(a).

(c) For general terms, such as *Indication, Flaw, Discontinuity, Evaluation*, etc., refer to Article 1, Mandatory Appendix I.

(d) Paragraph V-230(b) provides a list of terms and definitions that are Code specific. Paragraph V-230(c) provides a list of terms and definitions that are specific to Section V, Article 2, Appendix VI.

V-230 REQUIREMENTS

(a) The following SE-1316 terms are used in conjunction with this Article: *composite viewing, contrast sensitivity, contrast stretch, densitometer, density* (film), *digital image acquisition system, erasable optical medium, focal spot, intensifying screen, IQI sensitivity, line pair test pattern, location marker, luminosity, magnetic storage medium, optical density, pixel, pixel size, screen, source, step wedge, system-induced artifacts, transmission densitometer,* and *transmitted film density.*

(b) The following Code terms are used in conjunction with this Article.

annotate — to provide an explanatory note on the digital image

calibrated line pair test pattern — see *optical line pair test pattern*

calibrated step wedge film — a radiograph with discrete density steps, which is traceable to a national standard

cathode ray tube (soft display) — a device that produces an image by exciting a fluorescent substance with a magnetically guided beam

data compression — a reduction in the size of a digital data set to a smaller data set

density shift — a function that raises or lowers all density/greyscale values equally such that contrast is maintained within the data set

designated wire — the specific wire that must be discernible in the radiographic image of a wire-type image quality indicator

diaphragm — an aperture (opening) in a radiation opaque material that limits the usable beam size of a radiation source

digital — of, or relating to, data in the form of numerical digits (e.g., binary)

digitizing — the act of converting an analog measurement of a quantity to a digital value

display pixel size — the length and width dimensions of the smallest element of a displayed image

display system — a system that can display an array of pixels on a screen (CRT)

dynamic range — the range of operation of a device between its upper and lower limit; this range can be given as a ratio (e.g., 100:1) of the maximum signal level capability to its noise level, the number of measurable steps between the upper and lower limits, the number of bits needed to record this number of measurable steps, or the maximum and minimum measurable values

equivalent IQI sensitivity — that thickness of hole-type IQI, expressed as a percentage of the part thickness, in which $2T$ hole would be visible under the same radiographic conditions

essential hole — the specific hole that must be discernible in the radiographic image of a hole-type IQI

image processing system — a system that uses mathematical algorithms to manipulate digital image data

image quality indicator

hole type — a rectangular plaque, made of material radiographically similar to that of the object being radiographed, with small diameter holes (1*T*, 2*T*, and 4*T*) used to check the image quality of the radiograph

wire type — a set of small diameter wires, made of material radiographically similar to that of the object being radiographed, used to check the image quality of the radiograph

image storage system — a system that can store digital image data for future use

IQI — image quality indicator

line pair resolution — the number of line pairs per unit distance that are detectable in an image

log transform — a function that applies a logarithmic mapping to all density/greyscale values in an image; this operation is often performed when the resulting distribution is normal, or if the resulting relationship with another variable is linear

modulation transfer function (MTF) — a measure of spatial resolution as a function of contrast; a plot of these variables (spatial resolution and contrast) yields a curve representing the frequency response of the system

national standard step tablet — an x-ray film with discrete density steps produced and certified by a nationally recognized standardizing body

nonerasable optical media (optical disk) — a storage media that prevents the erasure or alteration of digital data after it is stored

optical density step wedge — a radiographic image of a mechanical step wedge with precise thickness increments and may be used to correlate optical film density to the thickness of material, also known as a step tablet

penetrameter — no longer used in Article 2; see *image quality indicator*

quantification — the act of determining or expressing a quantity (i.e., giving a numerical value to a measurement of something)

radiographic examination — a nondestructive method for detecting discontinuities in materials and components using penetrating radiation to produce an image on a recording medium

sensitivity — the smallest discernible detail and/or contrast change (e.g., IQI hole or wire) in a radiographic image

shim — a material, radiographically similar to the object being radiographed, that is placed between a hole-type IQI and the object in order to reduce the radiographic density through the image of the hole-type IQI

source side — that surface of the area of interest being radiographed for evaluation nearest the source of radiation

WORM (write once read many) — a term relating to a type of digital storage media where the data can be stored only once but accessed (nondestructively) many times

(c) The following Code terms are used in conjunction with Article 2, Appendix VI:

contrast sensitivity — the size of the smallest detectable change in optical density

dynamic range — the extent of measurable optical density obtained in a single scan

image — the digital representation of a target on the reference film used to evaluate both the digitization and display aspects of a film digitization system

reference film — a single industrial radiographic film that encompasses the targets necessary for the evaluation and quantification of the performance characteristics of a film digitization system

spatial linearity — the accuracy to which a digitization system reproduces the physical dimensions of information on the original film [both in the horizontal (along a single scan line) and vertical (from one scan line to another) directions]

spatial resolution — the size of the smallest detectable element of the digitized image

step wedge calibration film — a processed film with discrete density steps that have been verified by comparison with a national standard step tablet

step wedge comparison film — a processed film with discrete density steps that have been verified by use of a calibrated densitometer, which is used to determine if production radiographs meet density limits

target — a physical pattern on a reference film used to evaluate the performance of a film digitization system

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APPENDIX VI — DIGITAL IMAGE ACQUISITION, DISPLAY, INTERPRETATION, AND STORAGE OF RADIOGRAPHS FOR NUCLEAR APPLICATIONS

VI-210 SCOPE

Digital imaging process and technology provide the ability to digitize and store the detailed information contained in the radiograph (analog image), thus eliminating the need to maintain and store radiographs for permanent record.

VI-220 GENERAL REQUIREMENTS

VI-221 Supplemental Requirements

VI-221.1 Additional Information. Article 2, Mandatory Appendices III and IV, contain additional information that shall be used to supplement the requirements of this Appendix. These supplemental requirements shall be documented in the written procedure required by this Appendix.

VI-221.2 Reference Film. Supplement A contains requirements for the manufacture of the reference film.

VI-222 Written Procedure

A written procedure is required. The written procedure shall be the responsibility of the owner of the radiographs and shall be demonstrated to the satisfaction of the Authorized Nuclear Inspector (ANI). When other enforcement or regulatory agencies are involved, the agency approval is required by formal agreement. The written procedure shall include, as a minimum, the following essential variables:

VI-222.1 Digitizing System Description

(a) manufacturer and model no. of digitizing system;

(b) physical size of the usable area of the image monitor;

(c) film size capacity of the scanning device;

(d) spot size(s) of the film scanning system;

(e) image display pixel size as defined by the vertical/horizontal resolution limits of the monitor;

(f) luminance of the video display; and

(g) data storage medium.

VI-222.2 Digitizing Technique

(a) digitizer spot size (in microns) to be used (see VI-232);

(b) loss-less data compression technique, if used;

(c) method of image capture verification;

(d) image processing operations;

(e) time period for system verification (see VI-264);

(f) spatial resolution used (see VI-241);

(g) contrast sensitivity (density range obtained) (see VI-242);

(h) dynamic range used (see VI-243); and

(i) spatial linearity of the system (see VI-244).

VI-223 Personnel Requirements

Personnel shall be qualified as follows:

(a) Level II and Level III Personnel. Level II and Level III personnel shall be qualified in the radiographic method as required by Article 1. In addition, the employer's written practice shall describe the specific training and practical experience of Level II and Level III personnel involved in the application of the digital imaging process and the interpretation of results and acceptance of system performance. Training and experience shall be documented in the individual's certification records.

(b) As a minimum, Level II and III individuals shall have 40 hours of training and 1 month of practical experience in the digital imaging process technique.

(c) Other Personnel. Personnel with limited qualifications performing operations other than those required for the Level II or Level III shall be qualified in accordance with Article 1. Each individual shall have specified training and practical experience in the operations to be performed.

VI-230 EQUIPMENT AND MATERIALS

VI-231 System Features

The following features shall be common to all digital image processing systems:

(a) noninterlaced image display format;

(b) WORM — write-once/read-many data storage; and

(c) fully reversible (loss-less) data compression (if data compression is used).

VI-232 System Spot Size

The spot size of the digitizing system shall be:

(a) 70 microns, or smaller for radiographs made with energies up to 1 MeV; or

(b) 100 microns or smaller for radiographs made with energies over 1 MeV.

VI-240 SYSTEM PERFORMANCE REQUIREMENTS

System performance shall be determined using the digitized representation of the reference targets (images). No adjustment shall be made to the digitizing system which may affect system performance after recording the reference targets.

VI-241 Spatial Resolution

Spatial resolution shall be determined as described in VI-251. The system shall be capable of resolving a pattern of 7 line pairs/millimeter (lp/mm) for systems digitizing with a spot size of 70 microns or less, or 5 line pairs/millimeter for spot sizes greater than 70 microns.

VI-242 Contrast Sensitivity

Contrast sensitivity shall be determined as described in VI-252. The system shall have a minimum contrast sensitivity of 0.02 optical density.

VI-243 Dynamic Range

Dynamic range shall be determined as described in VI-253. The system shall have a minimum dynamic range of 3.5 optical density.

VI-244 Spatial Linearity

Spatial linearity shall be determined as described in VI-254. The system shall return measured dimensions with 3% of the actual dimensions on the reference film.

VI-250 TECHNIQUE

The reference film described in Supplement A and Fig. VI-A-1 shall be used to determine the performance of the digitization system. The system settings shall be adjusted to optimize the display representation of the reference targets (images). The reference film and all subsequent radiographs shall be scanned by the digitization system using these optimized settings.

VI-251 Spatial Resolution Evaluation

At least two of the converging line pair images (0 deg., 45 deg., and 90 deg. line pairs) shall be selected near the opposite corners of the digitizing field and one image near the center of the digitized reference film. The spatial resolution in each position and for each orientation shall be recorded as the highest indicated spatial frequency (as determined by the reference lines provided) where all of the lighter lines are observed to be separated by the darker lines. The system resolution shall be reported as the poorest spatial resolution obtained from all of the resolution images evaluated.

VI-252 Contrast Sensitivity Evaluation

Using the contrast sensitivity images and the digitized stepped density scale images to evaluate the detectability of each density step (the observed density changes shall be indicative of the system's capability to discern 0.02 density differences), the detectability of each density step and the difference in density between steps shall be evaluated.

VI-253 Dynamic Range Evaluation

The dynamic range of the digitization system shall be determined by finding the last visible density step at both ends of the density strip. The dynamic range shall be measured to the nearest 0.50 optical density.

VI-254 Spatial Linearity Evaluation

The digitization system shall be set to read the inch scale on the reference film. The measurement tool shall then be used to measure the scale in a vertical direction and horizontal direction. The actual dimension is divided

by the measured dimension to find the percentage of error in the horizontal and vertical directions.

VI-260 DEMONSTRATION OF SYSTEM PERFORMANCE

VI-261 Procedure Demonstration

The written procedure described in VI-222 shall be demonstrated to the ANI and, if requested, the regulatory agency, as having the ability to acquire, display, and reproduce the analog images from radiographs. Evidence of the demonstration shall be recorded as required by VI-291.

VI-262 Processed Targets

The digitizing process and equipment shall acquire and display the targets described in Supplement A. The digitally processed targets of the reference film shall be used to verify the system performance.

VI-263 Changes in Essential Variables

Any change in the essential variables identified in VI-222 and used to produce the results in VI-250 shall be cause for reverification of the System Performance.

VI-264 Frequency of Verification

The System Performance shall be initially verified in accordance with VI-262 at the beginning of each digitizing shift. Reverification in accordance with VI-262 shall take place at the end of each shift or at the end of 12 continuous hours, whichever is less, or at any time that malfunctioning is suspected.

VI-265 Changes in System Performance

Any evidence of change in the System Performance specified in VI-240 shall invalidate the digital images processed since the last successful verification and shall be cause for reverification.

VI-270 EXAMINATION

VI-271 System Performance Requirements

The digitizing system shall meet the requirements specified in VI-240 before digitizing archival radiographs.

VI-272 Artifacts

Radiographs shall be visually examined for foreign material and artifacts (e.g., scratches or water spots) in the area of interest. Foreign material not removed and artifacts observed shall be documented.

VI-273 Calibration

The calibration for a specific set of parameters (i.e., film size, density range, and spatial resolution) shall be conducted by following VI-240 and Supplement A. The results shall be documented.

VI-280 EVALUATION

VI-281 Process Evaluation

The Level II or Level III Examiner described in VI-223(a) shall be responsible for determining that the digital imaging process is capable of reproducing the original analog image. This digital image shall then be transferred to the write-once-read-many (WORM) optical disc.

VI-282 Interpretation

When interpretation of the radiograph is used for acceptance, the requirements of Article 2, Mandatory Appendix IV and the Referencing Code Section shall apply. If analog radiographs must be viewed in composite for acceptance, then both radiographs shall be digitized. The digital image of the analog radiographs shall be interpreted singularly.

VI-283 Baseline

Digital images of previously accepted radiographs may be used as a baseline for subsequent in-service inspections.

VI-290 DOCUMENTATION

VI-291 Reporting Requirements

The following shall be documented in a final report:

(a) spatial resolution (VI-241);

(b) contrast sensitivity (VI-242);

(c) frequency for system verification;

(d) dynamic range (VI-243);

(e) Traceability technique from original component to radiograph to displayed digital image, including original radiographic report(s). (The original radio-

graphic reader sheet may be digitized to fulfill this requirement);

(*f*) condition of original radiographs (VI-281);

(*g*) procedure demonstration (VI-261);

(*h*) spatial linearity (VI-244);

(*i*) system performance parameters (VI-241); and

(*j*) personnel performing the digital imaging process (VI-223).

VI-292 Archiving

When the final report and digitized information are used to replace the analog radiograph as the permanent record as required by the referencing Code Section, all information pertaining to the original radiography shall be documented in the final report and processed as part of the digital record. A duplicate copy of the WORM storage media is required if the radiographs are to be destroyed.

ARTICLE 2
MANDATORY APPENDIX VI — SUPPLEMENT A

VI-A-210 SCOPE

The reference film described in this supplement provides a set of targets suitable for evaluating and quantifying the performance characteristics of a radiographic digitizing system. The reference film is suitable for evaluating both the radiographic film digitization process and the electronic image reconstruction process.

The reference film shall be used to conduct performance demonstrations and evaluations of the digitizing system to verify the operating characteristics before radiographs are digitized. The reference film provides for the evaluation of spatial resolution, contrast sensitivity, dynamic range, and spatial linearity.

01 VI-A-220 GENERAL

VI-A-221 Reference Film

The reference film shall be specified in VI-A-230 and VI-A-240.

01 VI-A-230 EQUIPMENT AND MATERIALS

VI-A-231 Reference Targets

The illustration of the reference film and its targets is as shown in Fig. VI-A-1.

VI-A-232 Spatial Resolution Targets

The reference film shall contain spatial resolution targets as follows:

VI-A-232.1 Converging Line Pair Targets. Con- 01
verging line pairs shall consist of 3 identical groups of no less than 6 converging line pairs (6 light lines and 6 dark lines). The targets shall have a maximum resolution of no less than 20 line pairs per millimeter (lp/mm) and a minimum resolution of no greater than 1 lp/mm. The 3 line pair groups shall be oriented in the vertical, horizontal, and the last group shall be 45 deg. from the previous two groups. The maximum resolution shall be oriented toward the corners of the film. Reference marks shall be provided to indicate spatial resolution at levels of no less than 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, and 20 lp/mm. The spatial resolution targets shall be located in each corner of the needed film sizes.

VI-A-232.2 Parallel Line Pair Targets. Parallel line 01
pairs shall consist of parallel line pairs in at least the vertical direction on the reference film. It shall have a maximum resolution of at least 20 lp/mm and a minimum resolution of no less than 0.5 lp/mm. It shall have distinct resolutions of 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, and 20 lp/ mm and have the corresponding reference marks. It shall be located near the middle of the reference film.

VI-A-233 Constrast Sensitivity Targets 01

Contrast sensitivity targets shall consist of approximately 0.4 in. by 0.4 in. (10 mm by 10 mm) blocks centered in 1.6 in. by 1.6 in. (40 mm by 40 mm) blocks of a slightly lower density. Two series of these step blocks shall be used with an optical density of approximately 2.0 on a background of approximately 1.95, an optical density change of 0.05. The second block series will have an optical density of approximately 3.5 on a background of approximately 3.4, an optical density change of 0.10. The relative density change is more important than the absolute density. These images shall be located near the edges and the center of the film so as to test the contrast sensitivity throughout the scan path.

VI-A-234 Dynamic Range Targets 01

Stepped density targets shall consist of a series of 0.4 in. by 0.4 in. (10 mm by 10 mm) steps aligned in a row with densities ranging from 0.5 to 4.5 with no greater than 0.5 optical density steps. At four places

on the density strip (at approximately 1.0, 2.0, 3.0, and 4.0 optical densities), there shall be optical density changes of 0.02 which shall also be used to test the contrast sensitivity. These stepped density targets shall be located near the edges of the film and near the center so as to test the dynamic range throughout the scan path.

01 **VI-A-235 Spatial Linearity Targets**

Measurement scale targets shall be located in the horizontal and vertical dimensions. The measurement scale targets shall be in English and/or metric divisions.

01 **VI-A-240 MISCELLANEOUS REQUIREMENTS**

Manufacturing specifications shall be minimum requirements necessary for producing the reference film. The reference film shall have a unique identification which appears as an image when digitized.

VI-A-241 Material

The reference film shall be a fine grain, industrial type film. The film used will be of high quality so the required specifications in VI-A-230 are met.

VI-A-242 Film Size

The film size shall be sufficient to accommodate the largest area of interest to be digitized.

VI-A-243 Spatial Resolution

The spatial resolution shall be a minimum of 20 lp/mm.

VI-A-244 Density 01

The relative densities stated in VI-A-233 and VI-A-234 shall be within ±0.005 optical density.

(a) The tolerance for the optical density changes stated in VI-A-233 and VI-A-234 shall be ±0.005.

(b) The measured densities shall be within ±0.15 of the values stated in VI-A-233 and VI-A-234. The actual densities shall be recorded and furnished with the reference film.

(c) Density requirements shall be in accordance with ANSI IT-2.19.

(d) The background density, where there are no images located, shall have a 3.0 optical density ±0.5.

VI-A-245 Linearity

The measurement scale targets shall be accurately electronically produced to ±0.05 in. (±1.3 mm).

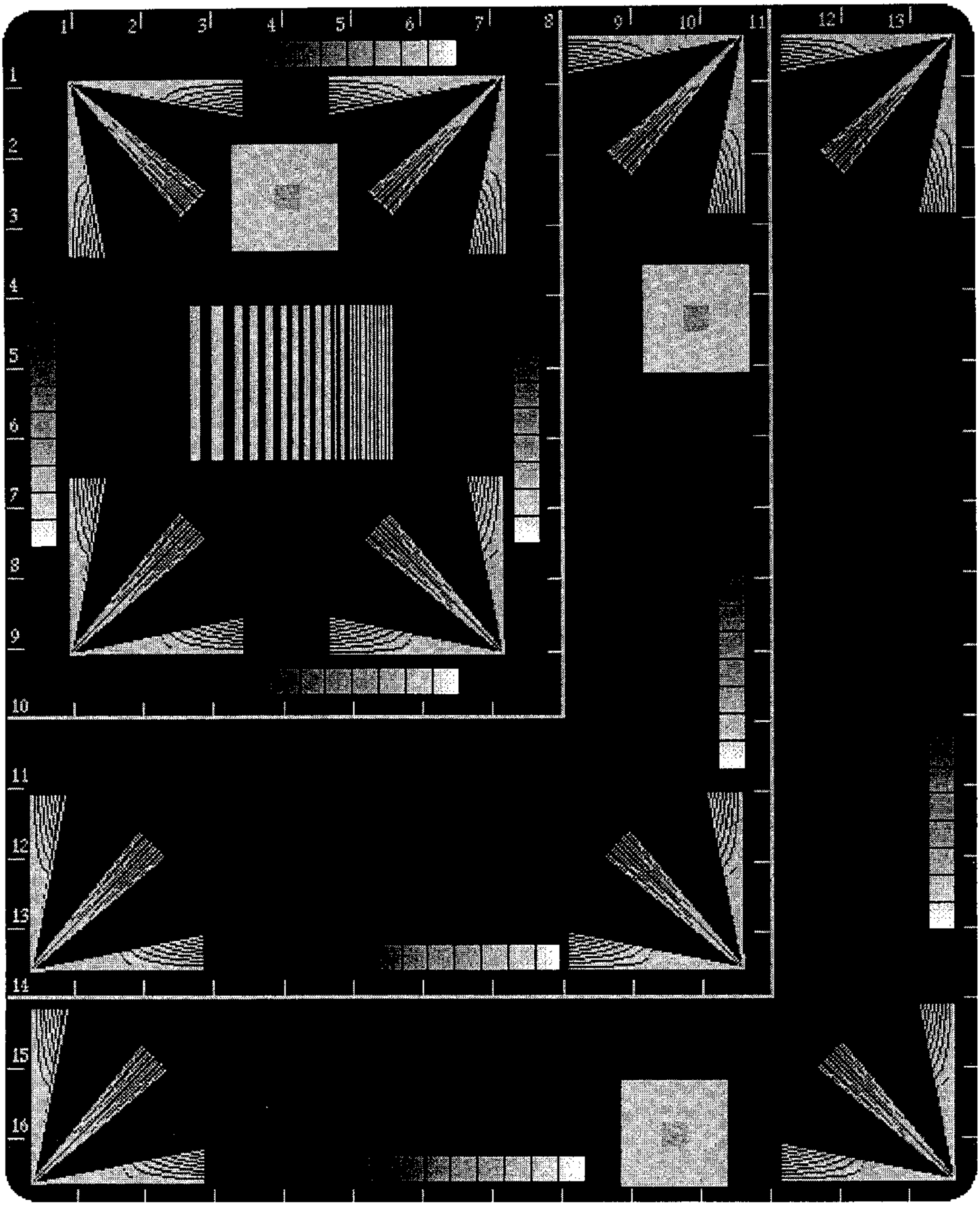


FIG. VI-A-1 REFERENCE FILM

ARTICLE 2
MANDATORY APPENDIX

APPENDIX VII — RADIOGRAPHIC EXAMINATION OF METALLIC CASTINGS

VII-210 SCOPE

Metallic castings, due to their inherent complex configurations, present examination conditions that are unique to this product form.

Radiographic examination may be performed on castings when the modified provisions to Article 2, as indicated herein, are satisfied.

VII-220 GENERAL REQUIREMENTS

VII-224 System of Identification

A system shall be used to produce permanent identification on the radiograph traceable to the contract, component, or part numbers, as appropriate. In addition, each film of a casting being radiographed shall be plainly and permanently identified with the name or symbol of the Material Manufacturer, Certificate Holder, or Subcontractor, job or heat number, date, and, if applicable, repairs (R1, R2, etc.). This identification system does not necessarily require that the information appear as radiographic images. In any case, this information shall not obscure the area of interest.

VII-270 EXAMINATION

VII-271 Radiographic Technique

VII-271.2 Double-Wall Viewing Technique. A double-wall viewing technique may be used for cylindrical castings $3\frac{1}{2}$ in. (89 mm) or less in O.D. or when the shape of a casting precludes single-wall viewing.

VII-276 IQI Selection

VII-276.3 Additional IQI Selection Requirements. The thickness on which the IQI is based is the single-wall thickness.

(a) Casting Areas Prior to Finish Machining. The IQI shall be based on a thickness that does not exceed the finished thickness by more than 20% or $\frac{1}{4}$ in. (6.4 mm), whichever is greater. In no case shall an IQI size be based on a thickness greater than the thickness being radiographed.

(b) Casting Areas That Will Remain in the As-Cast Condition. The IQI shall be based on the thickness being radiographed.

VII-280 EVALUATION

VII-282 Radiographic Density

VII-282.1 Density Limitations. The transmitted film density through the radiographic image of the body of the appropriate hole IQI or adjacent to the designated wire of a wire IQI and the area of interest shall be 1.5 minimum for single film viewing. For composite viewing of multiple film exposures, each film of the composite set shall have a minimum density of 1.0. The maximum density shall be 4.0 for either single or composite viewing. A tolerance of 0.05 in density is allowed for variations between densitometer readings.

VII-290 DOCUMENTATION

VII-293 Layout Details[1]

To assure that all castings are radiographed consistently in the same manner, layout details shall be provided. As a minimum, the layout details shall include:

(a) sketches of the casting, in as many views as necessary, to show the approximate position of each location marker; and

(b) source angles if not perpendicular to the film.

[1] Sample layout and technique details are illustrated in SE-1030, Appendix (Nonmandatory Information) X1, Fig. X1.1, Radiographic Standard Shooting Sketch (RSS).

ARTICLE 2
NONMANDATORY APPENDIX

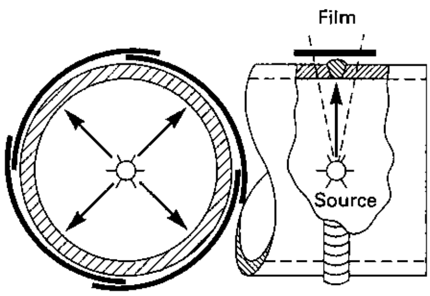
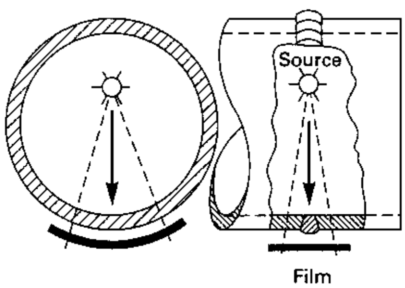
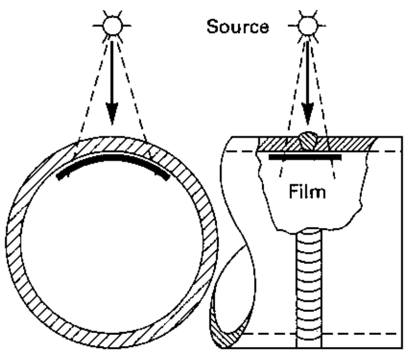
APPENDIX A — TECHNIQUE SKETCHES FOR PIPE OR TUBE WELDS

A-210 SCOPE

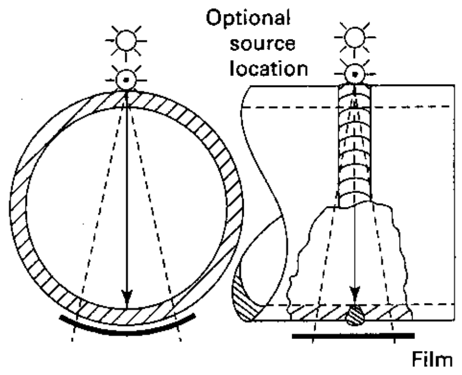
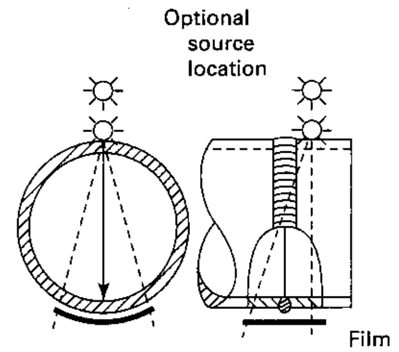
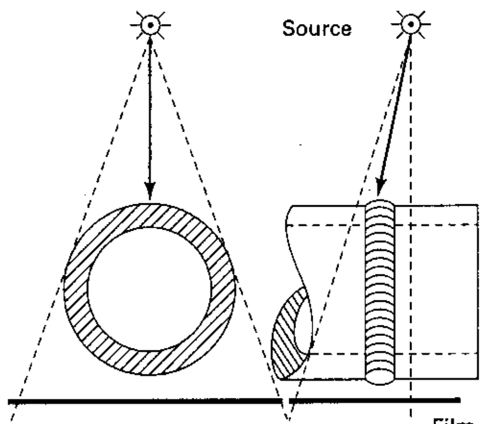
The sketches in the Appendix illustrate techniques used in the radiographic examination of pipe or tube welds.

Other techniques may be used.

SINGLE-WALL RADIOGRAPHIC TECHNIQUES

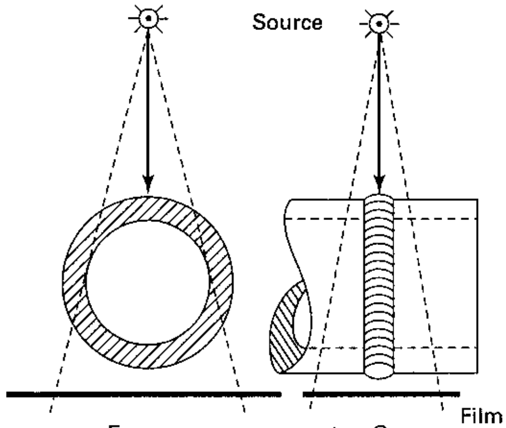
Pipe O.D.	Exposure Technique	Radiograph Viewing	Source-Weld-Film Arrangement		IQI		Location Marker Placement
			End View	Side View	Selection	Placement	
Any	Single-Wall T-271.1	Single-Wall	 Exposure Arrangement — A		T-276 and Table T-276	Source Side T-277.1(a) Film Side T-277.1(b)	Either Side T-275.3 T-275.1(c)
Any	Single-Wall T-271.1	Single-Wall	 Exposure Arrangement — B		T-276 and Table T-276	Source Side T-277.1(a) Film Side T-277.1(b)	Film Side T-275.1 (b)(1)
Any	Single-Wall T-271.1	Single-Wall	 Exposure Arrangement — C		T-276 and Table T-276	Source Side T-277.1(a) Film Side T-277.1(b)	Source Side T-275.1 (a)(3)

DOUBLE-WALL RADIOGRAPHIC TECHNIQUES

Pipe O.D.	Exposure Technique	Radiograph Viewing	Source-Weld-Film Arrangement: End View	Source-Weld-Film Arrangement: Side View	IQI: Selection	IQI: Placement	Location Marker Placement
Any	Double-Wall: T-271.2(a) at Least 3 Exposures 120 deg. to Each Other for Complete Coverage	Single-Wall	 Exposure arrangement — D		T-276 and Table T-276	Source Side T-277.1(a) Film Side T-277.1(b)	Film Side T-275.1 (b)(1)
Any	Double-Wall: T-271.2(a) at least 3 Exposures 120 deg. to Each Other for Complete Coverage	Single-Wall	 Exposure arrangement — E		T-276 and Table T-276	Source Side T-277.1(a) Film Side T-277.1(b)	Film Side T-275.1 (b)(1)
$3\frac{1}{2}$ in. (89 mm) or Less	Double-Wall T-271.2(b)(1) at Least 2 Exposures at 90 deg. to Each Other for Complete Coverage	Double-Wall (Ellipse): Read Offset Source Side and Film Side Images	 Exposure arrangement — F		T-276 and Table T-276	Source Side T-277.1(a)	Either Side T-275.2

(continued)

DOUBLE-WALL RADIOGRAPHIC TECHNIQUES (CONT'D)

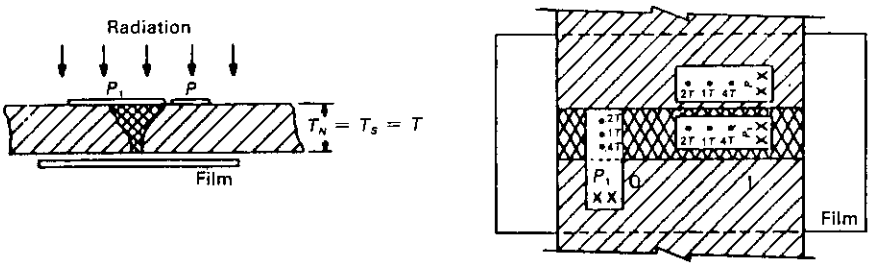
			Source-Weld-Film Arrangement		IQI		Location Marker Placemen t
Pipe O.D.	Exposure Technique	Radiograph Viewing	End View	Side View	Selection	Placement	
in. (89 mm) or Less	Double-Wall: T-271.2(b)(2) at Least 3 Exposures at 60 deg. or 120 deg. to Each Other for Complete Coverage	Double-Wall: Read Super-imposed Source Side and Film Side Images	 Exposure arrangement — G		T-276 and Table T-276	Source Side T-277.1(a)	Either Side T-275.2

ARTICLE 2
NONMANDATORY APPENDIX

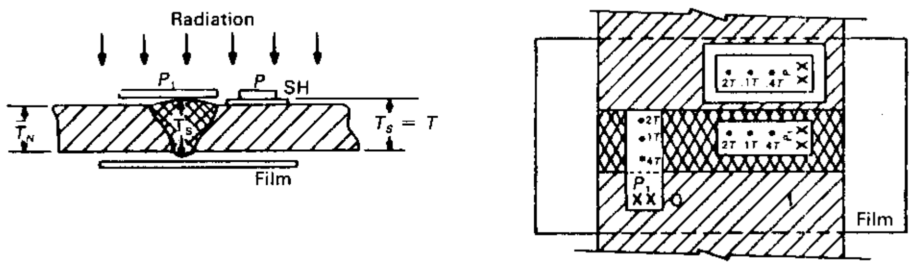
APPENDIX C — HOLE-TYPE IQI PLACEMENT SKETCHES FOR WELDS

C-210 SCOPE

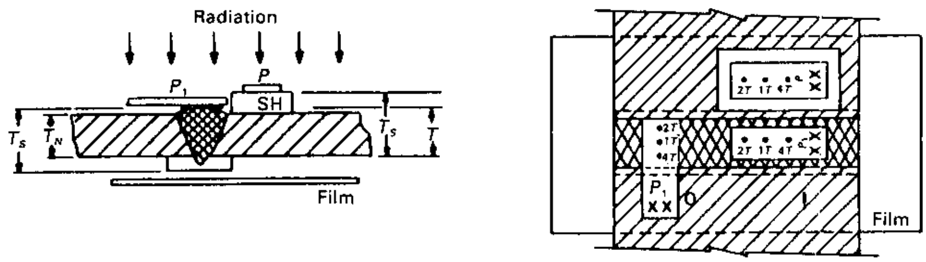
The figures in this Appendix demonstrate typical IQI (hole type) placement for welds. These sketches are tutorial to demonstrate suggested locations of IQIs and are not intended to cover all configurations or applications of production radiography. Other IQI locations may be used provided they comply with the requirements of Article 2. Wire IQIs shall be placed in accordance with the requirements of Article 2.



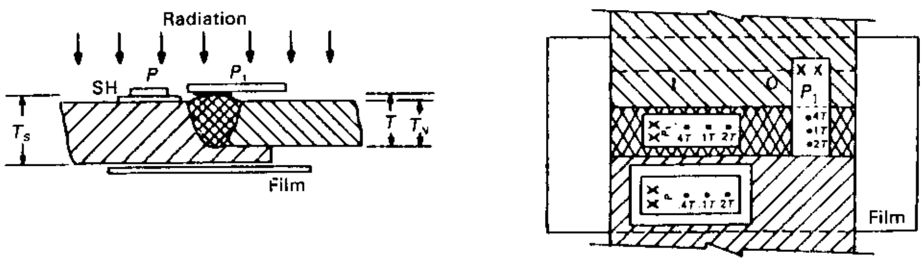
(a) Single Wall, No Reinforcement, No Back-Up Strip



(b) Single Wall, Weld Reinforcement, No Back-Up Strip



(c) Single Wall, Weld Reinforcement, Back-Up Strip



(d) Single Wall, Integral Backing Ring, Weld Reinforcement

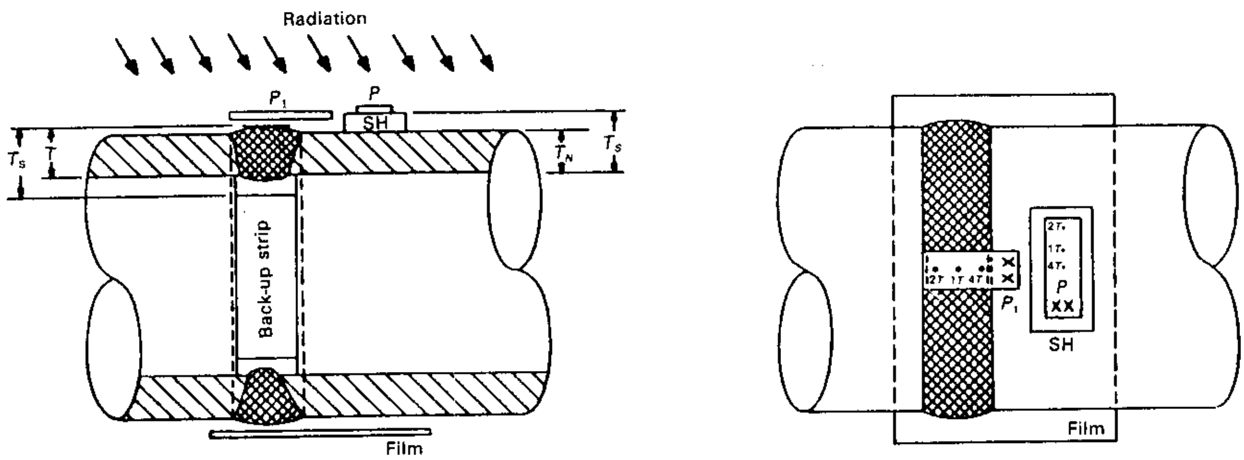
GENERAL NOTE:

P and P_1 are suggested placements of IQIs and are not intended to cover all geometric configurations or applications of production radiography.

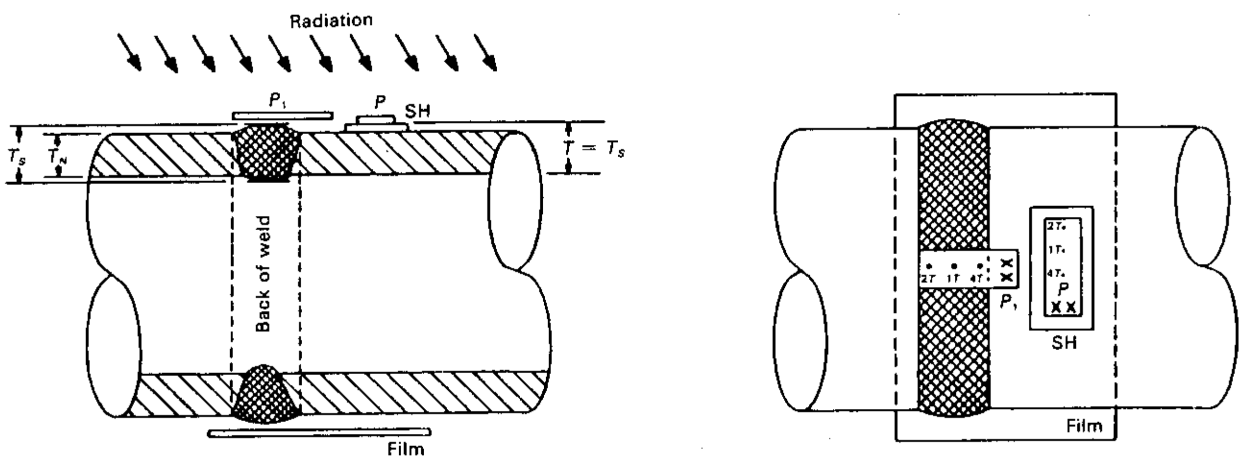
LEGEND:

P = IQI placement
P_1 = alternate IQI placement
SH = shim
T = weld thickness upon which the IQI is based
T_N = nominal wall thickness
T_S = total thickness including backing strip and/or reinforcement when not removed

FIG. C-210-1 SIDE AND TOP VIEWS OF HOLE-TYPE IQI PLACEMENTS



(a) Double-Wall Technique, Double-Wall Viewing, With Weld Reinforcement and Back-Up Strip



(b) Double-Wall Technique, Double-Wall Viewing, With Weld Reinforcement and No Back-Up Strip

GENERAL NOTES:

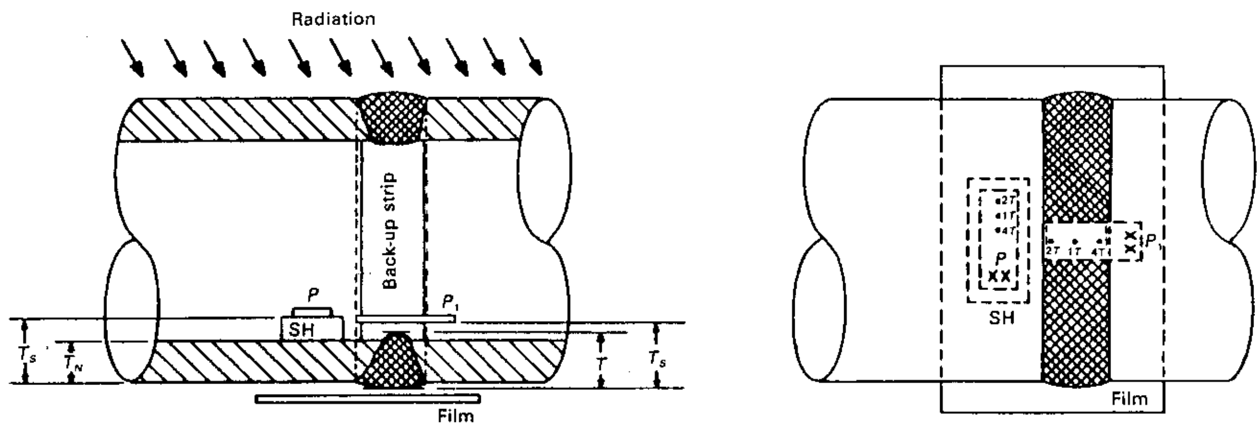
(a) P and P_1 are suggested placements of IQIs and are not intended to cover all geometric configurations or applications of production radiography.

(b) IQI is based on the single-wall thickness plus reinforcement.

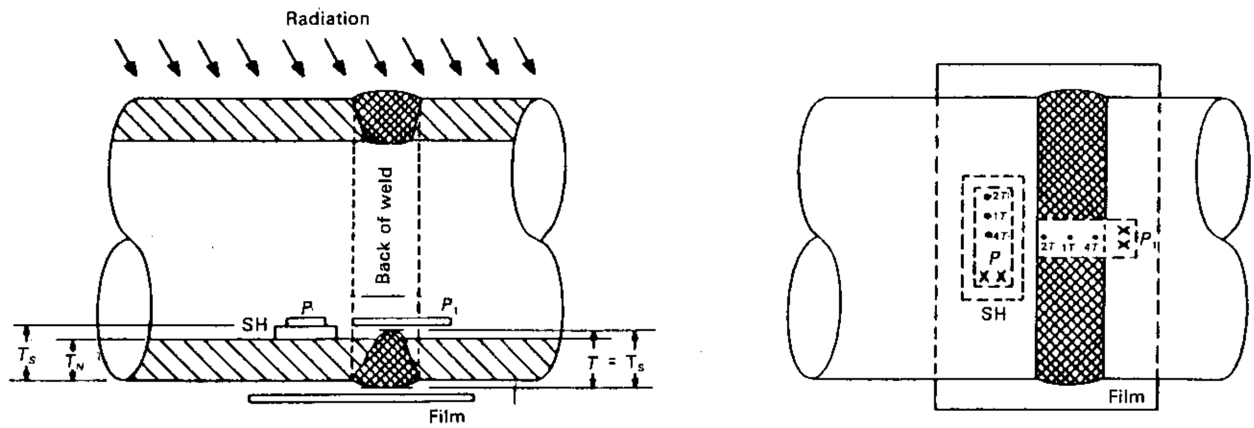
LEGEND:

P = IQI placement
P_1 = alternate IQI placement
SH = shim
T = weld thickness upon which the IQI is based
T_N = nominal wall thickness
T_S = total thickness including backing strip and/or reinforcement when not removed

FIG. C-210-2 SIDE AND TOP VIEWS OF HOLE-TYPE IQI PLACEMENTS



(a) Double-Wall Technique, Single-Wall Viewing, Back-Up Strip



(b) Double-Wall Technique, Single-Wall Viewing, Wall Reinforcement, No Back-Up Strip

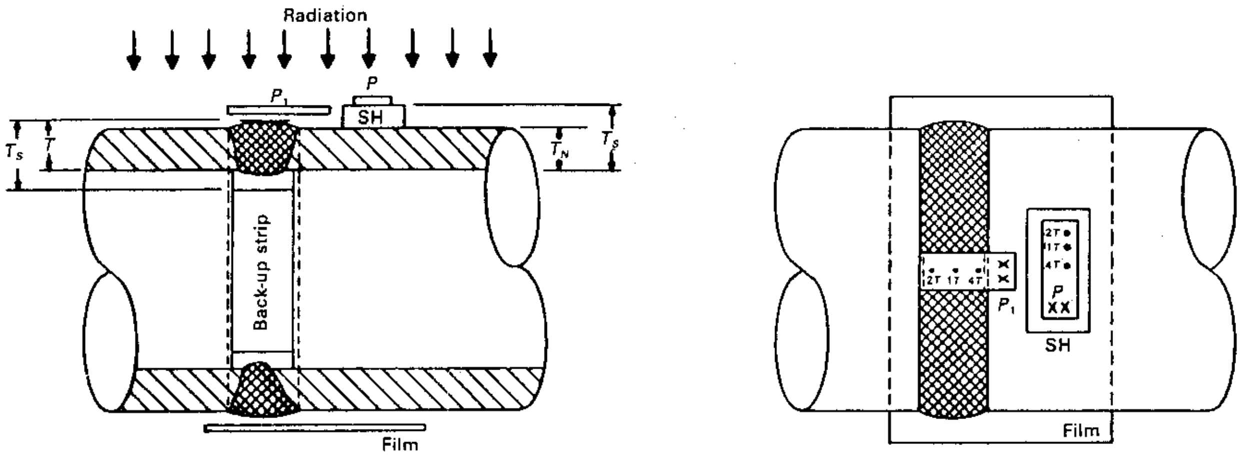
GENERAL NOTE:

P and P_1 are suggested placements of IQIs and are not intended to cover all geometric configurations or applications of production radiography.

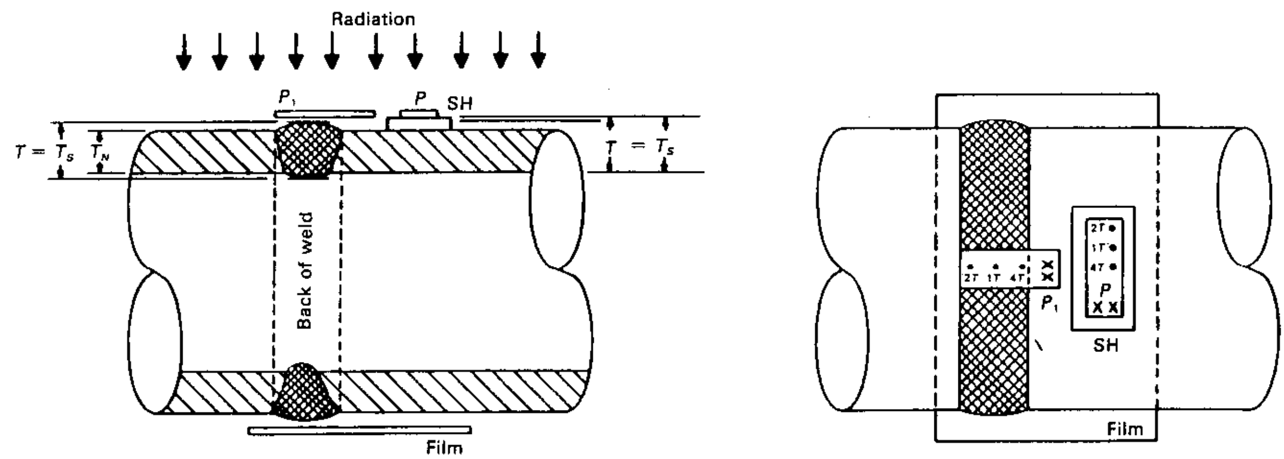
LEGEND:

P = IQI placement
P_1 = alternate IQI placement
SH = shim
T = weld thickness upon which the IQI is based
T_N = nominal wall thickness
T_S = total thickness including backing strip and/or reinforcement when not removed

FIG. C-210-3 SIDE AND TOP VIEWS OF HOLE-TYPE IQI PLACEMENTS



(a) Double-Wall Technique, Double-Wall Viewing, With Weld Reinforcement and Back-Up Strip



(b) Double-Wall Technique, Double-Wall Viewing, With Weld Reinforcement and No Back-Up Strip

GENERAL NOTES:

(a) P and P_1 are suggested placements of IQIs and are not intended to cover all geometric configurations or applications of production radiography.

(b) IQI is based on the single-wall thickness plus reinforcement.

LEGEND:

P = IQI placement
P_1 = alternate IQI placement
SH = shim
T = weld thickness upon which the IQI is based
T_N = nominal wall thickness
T_S = total thickness including backing strip and/or reinforcement when not removed

FIG. C-210-4 SIDE AND TOP VIEWS OF HOLE-TYPE IQI PLACEMENTS

ARTICLE 2
NONMANDATORY APPENDIX

APPENDIX D — NUMBER OF IQIs (SPECIAL CASES)

D-210 SCOPE

The figures in this Appendix illustrate examples of the number and placement of IQIs that may be used in the special cases described in T-277.2(b). These figures are not intended to cover all configurations or applications of production radiography.

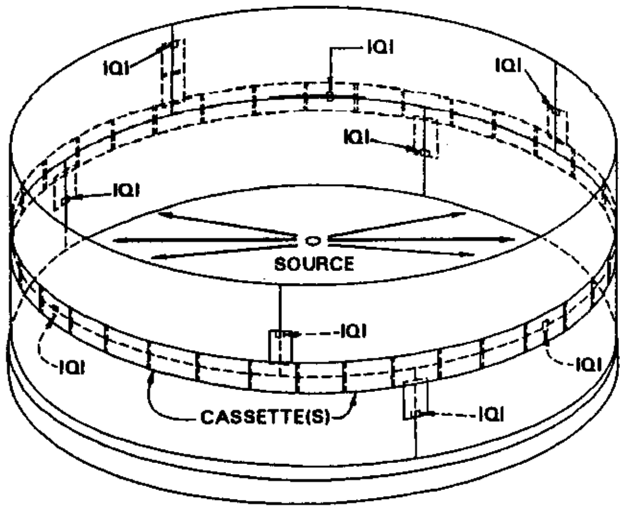


FIG. D-210-1 COMPLETE CIRCUMFERENCE CYLINDRICAL COMPONENT [T-277.2(b)(1)(a) & T-277.2(b)(3)]

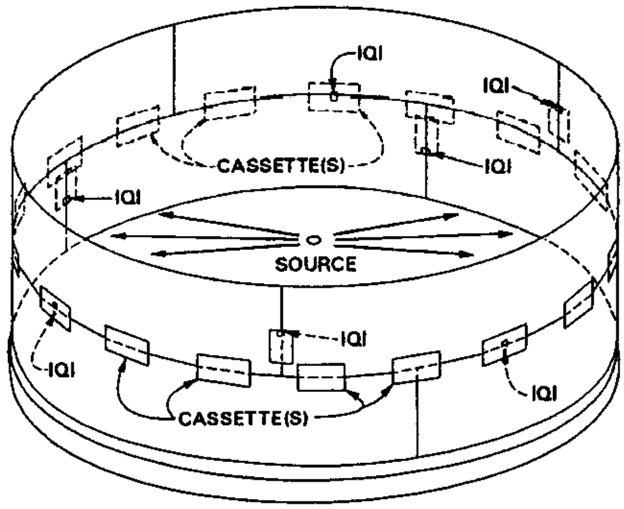


FIG. D-210-2 SECTION OF CIRCUMFERENCE 240 deg. OR MORE CYLINDRICAL COMPONENT (EXAMPLE IS ALTERNATE INTERVALS) [T-277.2(b)(1)(b) & T-277.2(b)(3)]

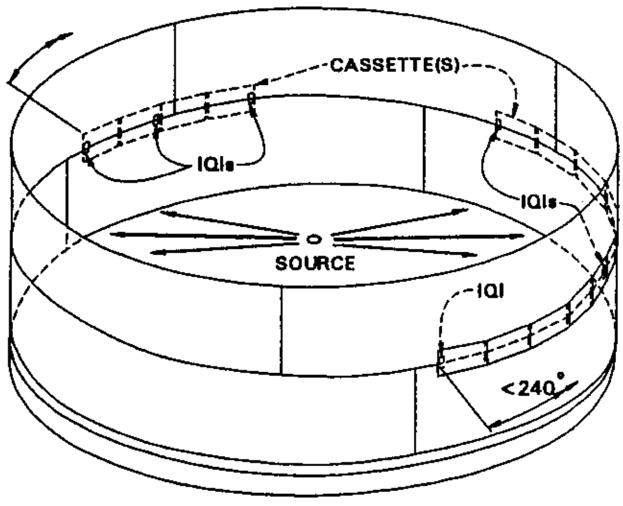


FIG. D-210-3 SECTION(S) OF CIRCUMFERENCE LESS THAN 240 deg. CYLINDRICAL COMPONENT [T-277.2(b)(2)(b)]

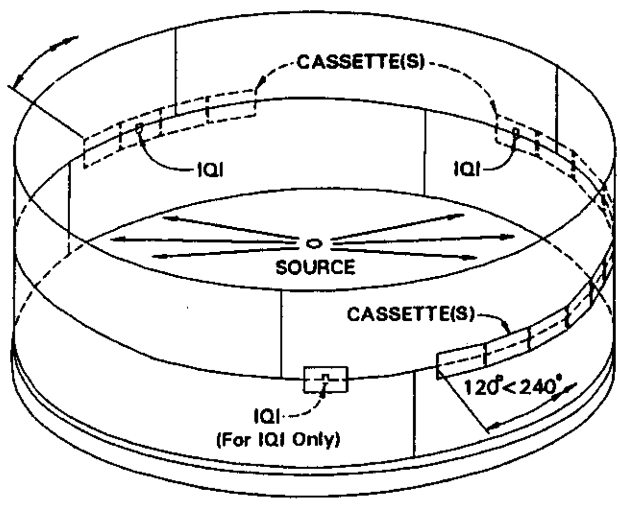


FIG. D-210-4 SECTION(S) OF CIRCUMFERENCE EQUAL TO OR MORE THAN 120 deg. AND LESS THAN 240 deg. CYLINDRICAL COMPONENT [T-277.2(b)(2)(b) OPTION]

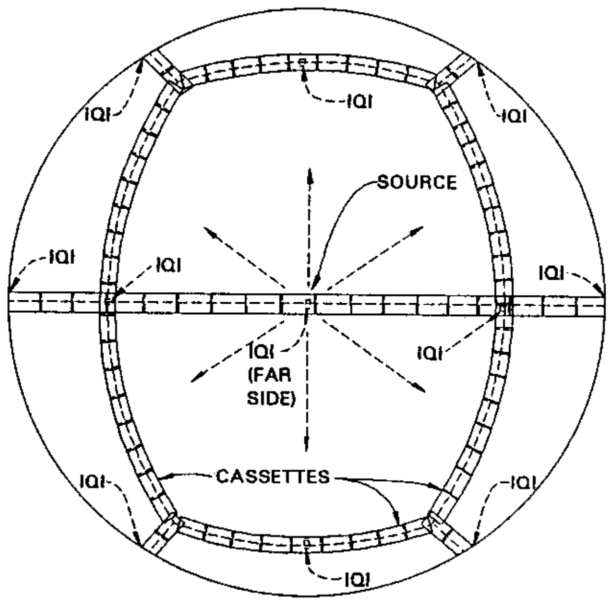


FIG. D-210-5 COMPLETE CIRCUMFERENTIAL WELDS SPHERICAL COMPONENT [T-277.2(b)(4)(a) & T-277.2(b)(6)]

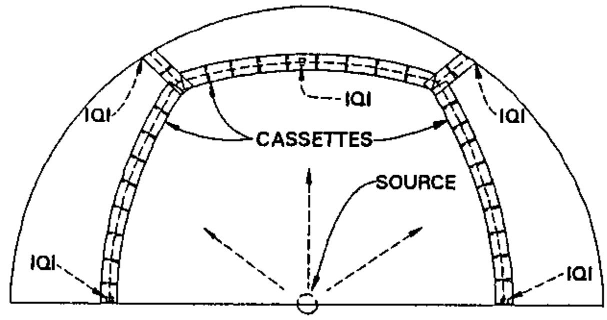


FIG. D-210-6 WELDS IN SEGMENTS OF SPHERICAL COMPONENT [T-277.2(b)(5) & T-277.2(b)(5)(b) & T-277.2(b)(6)]

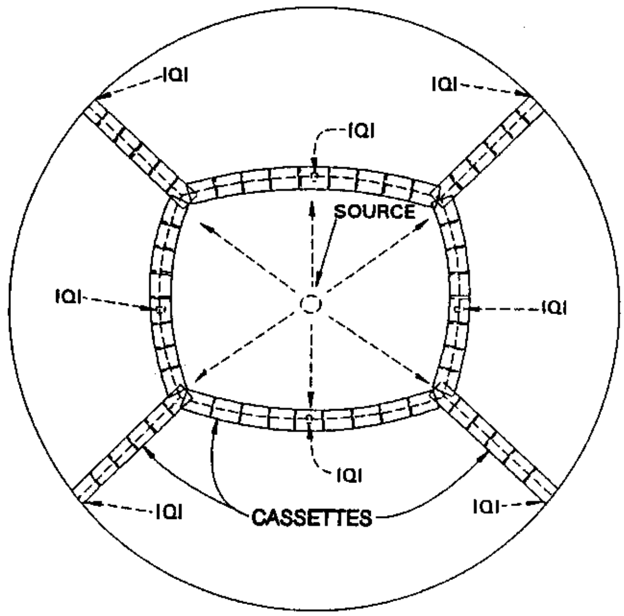
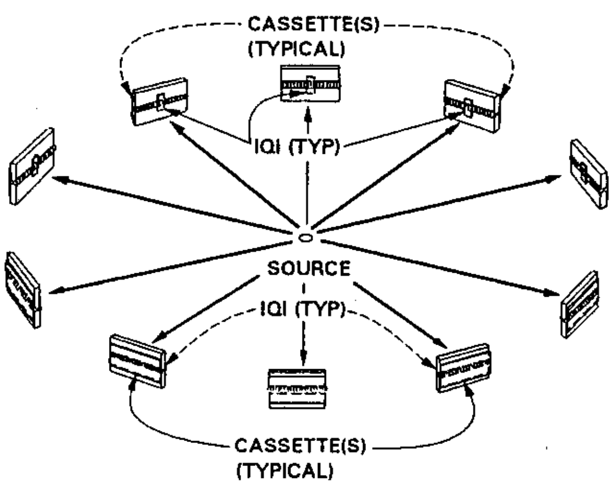


FIG. D-210-7 PLAN VIEW A-A



Note: Special Cases IQI Locations are Typical in All Figures.

FIG. D-210-8 ARRAY OF OBJECTS IN A CIRCLE [T-277.2(b)(7)]

ARTICLE 4

Mandatory Appendices

Figure

Nonmandatory Appendices

Figures

Tables

ARTICLE 4
ULTRASONIC EXAMINATION METHODS FOR INSERVICE INSPECTION

T-410 SCOPE

This Article describes or references requirements which are to be used in selecting and developing [see T-110(c)] ultrasonic examination procedures when examination to any part of this Article is a requirement of a referencing Code Section. These procedures are to be used for the ultrasonic examination and the dimensioning of indications for comparison with acceptance standards when required by the referencing Code Section; the referencing Code Section shall be consulted for specific requirements for the following:

Personnel Qualification/Certification Requirements

Procedure Requirements/Demonstration, Qualification, Acceptance

Examination System Characteristics

Retention and Control of Calibration Blocks

Extent of Examination and/or Volume to Be Scanned

Acceptance Standards to Be Used for Evaluation

Retention of Records

Report Requirements

T-420 GENERAL

T-421 Basic Requirements and Terms Used

When this Article is specified by a referencing Code Section, the ultrasonic method described in this Article shall be used together with Article 1, General Requirements. Definitions of terms used in this Article are in Mandatory Appendix III of Article 5.

T-422 Personnel Requirements

The user of this Article shall be responsible for assigning qualified personnel to perform ultrasonic examination to the requirements of this Article. Personnel performing this examination shall be qualified as required by the referencing Code Section.

T-423 Procedure Requirements 01

Ultrasonic examination shall be performed in accordance with a written procedure.

T-424 General Examination Requirements

T-424.1 Examination Coverage. The volume shall be examined by moving the search unit over the examination volume. As a minimum, each pass of the search unit shall overlap a minimum of 50% of the transducer (piezoelectric element) dimension perpendicular to the direction of the scan. Alternatively, each pass of the search unit shall overlap a dimension less than the minimum beam dimension as determined in Appendix B, B-60, Beam Spread. Oscillation of the search unit is permitted provided improved coverage is demonstrated.

T-424.2 Rate of Search Unit Movement and Pulse Repetition Rate. The ultrasonic instrument pulse repetition rate shall be sufficient to pulse the search unit at least six times within the time necessary to move one-half the transducer (piezoelectric element) dimension parallel to the direction of the scan at maximum scanning speed. Alternatively, a dynamic calibration multiple reflectors that is within ±2dB of a static calibration may be used to verify an acceptable pulse repetition rate.

T-424.3 Scanning Sensitivity Level. For both manual and mechanized examinations, recording of indications shall be made at scan sensitivity. During scanning only the gain or attenuator controls may be adjusted. Any adjustments to the other controls shall require recalibration.

T-430 EQUIPMENT

T-431 Instrument Requirements

T-431.1 Type. A pulse-echo type of ultrasonic instrument shall be used. The instrument shall be equipped

with a stepped gain control calibrated in units of 2.0 dB or less.

T-434 Search Unit Requirements

T-434.1 Beam Spread Measurement. Measurements of beam spread for scan indexing limits shall be taken only when required by a Referencing Code Section. Measurements of angle beam search units shall be performed once for a search unit wedge combination in the calculated far field at the beginning of each period of extended use (or every 3 months, whichever is less). A technique for beam spread is given in Appendix B, Section B-60. Other techniques may be used.

T-435 Basic Calibration Block(s)

If the qualified procedure calls for a basic calibration block, Appendix J provides a description of one design of block. Other calibration block designs may be used.

T-436 Computerized Imaging Techniques

The major attribute of computerized imaging techniques (CITs) is their effectiveness when used to characterize and evaluate indications; however, CITs may also be used to perform the basic scanning functions required for flaw detection. Computer processed data analysis and display techniques are used in conjunction with automated scanning mechanisms to produce two and three dimensional images of flaws which provides an enhanced capability for examining critical components and structures. Computer processes may then be used to quantitatively evaluate the type, size, shape, location, and orientation of flaws detected by ultrasonic examination or other NDE methods. Descriptions for some techniques that may be used in computerized imaging are provided in Nonmandatory Appendix E.

T-440 REQUIREMENTS

T-441 Vessel Examinations

T-441.1 Scanning Requirements

T-441.1.1 General Scanning Requirements. The volume of weld and adjacent base material (volume on either side of the weld seam) that is to be examined shall be as required by the referencing Code Section. These volumes shall be scanned using qualified techniques.

T-441.1.2 Scan for Interference With Angle Beam Examination. Prior to the initial angle beam examination, the base material through which the angle beams will travel shall be scanned with a straight beam search unit [(b) below] to detect laminar reflectors which might affect the interpretation of angle beam results. These examination data shall be recorded.

(a) Straight Beam Scanning for Planar Reflectors. The examination for planar reflectors shall be performed on the entire volume of weld and adjacent base material to the extent required by the referencing Code Section. The calibration shall be performed as described in T-462. Penetration shall be verified by obtaining a reflection from an opposite surface of the material being examined when the two surfaces are parallel.

(b) Straight Beam Scanning for Laminar Reflectors. Scanning for laminar reflectors shall be performed at a gain setting that gives an initial back reflection amplitude of 80% (±5% of full screen height) of screen height from the component. When the examination is performed from the tapered surface at a transition in thickness of the component, angle beam longitudinal waves traveling essentially perpendicular to the back surface may be used to maintain the back reflection.

T-441.1.3 Extent of Scanning. Wherever feasible, the scanning of the examination volume shall be carried out from both sides of the weld on the same surface. Where configuration or adjacent parts of the component are such that scanning from both sides is not feasible, this fact shall be included in the report of the examination.

T-441.1.4 Angle Beam Scanning. The calibration shall be performed as described in T-460. The examination volume shall be scanned with angle beam search units directed both at right angles to the weld axis and along the weld axis. Wherever feasible, each examination shall be performed in two directions, i.e., approaching the weld from opposite directions and parallel to the weld from opposite directions.

T-441.1.5 Scanning for Reflectors Oriented Parallel to the Weld. The angle beam search units shall be aimed at right angles to the weld axis, with the search unit manipulated so that the ultrasonic beams pass through the entire volume of weld metal. The adjacent base metal in the examination volume must be completely scanned by two angle beams, but need not be completely scanned by both angle beams from both directions (any combination of two angle beams will satisfy the requirement). Where the ultrasonic beams are directed essentially normal to the plane of the weld (parallel to the surface of the material, as when the examination is conducted from the nozzle bore or flange face), beam angles sufficient to provide

complete coverage of the weld from one direction shall be acceptable. The additional $^1/_4$ volume angle beam examination shall comply with these requirements within one-fourth of the thickness from the examination surface.

T-441.1.6 Scanning for Reflectors Oriented Transverse to the Weld. The angle beam search units shall be aimed parallel to the axis of longitudinal and circumferential welds. The search unit shall be manipulated so that the ultrasonic beams pass through all of the examination volume. Scanning shall be done in two directions 180 deg. to each other to the extent possible. Areas blocked by geometric conditions shall be examined from at least one direction. The additional $^1/_4$ volume angle beam examination shall comply with these requirements within one-fourth of the thickness from the examination surface.

T-441.1.7 Recording Angle Beam Examination Data for Planar Reflectors. Appendix H contains a method of recording angle beam exam data. Other qualified methods may be used.

T-441.1.8 Recording Examination Data for Planar Straight Beam Reflectors. Appendix K contains a method of recording straight beam exam data. Other qualified methods may be used.

T-441.1.9 Recording Straight Beam Examination Data for Laminar Reflectors

(a) Recording of Laminar Reflectors for Interference With Angle Beam Examination. Record all areas giving indications equal to or greater than the remaining back reflection.

(b) Recording of Laminar Reflectors for Acceptance. Record all areas where one or more discontinuities produce a continuous total loss of back reflection accompanied by continuous indications in the same plane.

(c) Data Required. The following data shall be recorded: sweep reading of laminar reflectors from surface, position from reference line, and location parallel to the reference line for each search unit position giving the recordable extent of the indication, as the "laminar" area is scanned on parallel scan paths.

T-442 Examination of Nozzle Inner Radius and Inner Corner Regions

T-442.1 General. This paragraph describes the requirements for ultrasonic examination of nozzle inner radius and inner corner regions. The requirements described here are used on ferritic materials greater than 2 in. (51 mm) in thickness to detect, locate, and determine the dimensions of reflectors within the examination area.

T-442.2 Surface Preparation. The examination surfaces shall be free of irregularities, loose foreign matter, or coatings which interfere with ultrasonic wave transmission.

T-442.3 Identification of Examination Areas

(a) Examination Area Locations. Identification and location shall be shown on an identification plan.

(b) Marking. If examination areas are permanently marked by low-stress stamps and/or vibratooling, the marking shall be in accordance with the referencing Code requirements.

(c) Referencing System. Each examination area shall be located and identified by a system of referencing points placed on the component. The system shall permit identification of each examination area and designation of regular intervals along the length of the area. A typical system for layout is described in Appendix A; however, a different system may be utilized provided it meets the above requirements.

T-442.4 Scanning Requirements

T-442.4.1 General Scanning Requirements. The examination volume shall be as required by the referencing Code Section. These volumes shall be scanned by qualified ultrasonic techniques. Nonmandatory Appendix F provides guidelines for procedure and technique qualification, but other qualification methods may be used.

T-442.4.2 Scan for Interference With Examination. When examining from the external surfaces and prior to the initial examination, the base material through which the examination beams will travel shall be scanned to detect reflectors which might affect the interpretation of examination results. This examination data shall be recorded.

Scanning for reflectors shall be performed at a gain setting that gives an initial back reflection amplitude of 80% (±5% of full screen height) of screen height from the component. When the examination is performed from the tapered surface at a transition in thickness of the component, angle beam waves traveling essentially perpendicular to the back surface may be used to maintain the back reflection.

T-442.4.3 Extent of Scanning. Scanning of the entire examination volume shall be performed as possible. Where configurations or adjacent parts of the component are such that scanning the entire area is not feasible, this fact shall be included in the report of the examination.

T-442.4.4 Scanning for Planar Flaws. The examination volume shall be scanned such that the anticipated flaws will be intercepted by the sound beams in a manner that will allow detection. Wherever feasible, each examination shall be performed in two directions.

T-442.4.5 Recording Examination Data for Planar Reflectors Using Amplitude-Based Technique

(a) When amplitude-based technique is used, record all reflectors that produce a response equal to or greater than 20% of the primary reference response (PRR). However, the clad interface metallurgical reflectors and back wall reflections need not be recorded. Record all search unit position and location dimensions to the nearest tenth of an inch.

(b) Obtain data from successive scans at increments no greater than 50% of the transducer dimension measured parallel to the scan increment change at the examination area. Record data for the end points as determined by 20% PRR. Emphasis must be placed on measurement of the parameters determining the reflector length and height and the distances from the examination surface to the top and bottom of the reflector, since these dimensions are the factors most critical in determining ultimate evaluation and disposition of the flaw (see Appendix D for an illustrated example).

(c) The following reflector data shall be recorded when a reflector exceeds 20% PRR.

(1) Maximum percent of PRR, sweep reading of indication, search unit position, and beam direction.

(2) For reflectors 20 to 100% PRR, the minimum sweep reading and the search unit position along the length of the reflector for 20% PRR when approaching the reflector from the maximum signal direction.

(3) For reflectors 20 to 100% PRR, maximum sweep reading and the search unit position along the length of the reflector for 20% PRR when moving away from the reflector's maximum signal direction.

(4) For reflectors exceeding 100% PRR, minimum sweep reading and the search unit position along the length of the reflector for 50% of the maximum amplitude when approaching the reflector from the maximum signal direction.

(5) For reflectors exceeding 100% PRR, minimum sweep reading and the search unit position along the length of the reflector for 50% of the maximum amplitude when moving away from the reflector's maximum signal direction.

(6) The length of the reflector shall be obtained by recording the positions of each end of the reflector at 20% PRR.

T-442.4.6 Recording Examination Data for Planar Reflectors Using Non-Amplitude-Based Techniques. When examinations are performed using non-amplitude-based techniques, indication recording requirements shall be specified in the examination procedure.

T-442.4.7 Recording Data for Reflectors Which Interfere With Examination

(a) Record all areas giving indications equal to or greater than the remaining back reflection.

(b) The following data shall be recorded: sweep reading of reflectors from surface, position from reference, and location parallel to reference for each search unit position giving the recordable extent of the indication.

T-444 Pumps and Valves (Including Welds)

T-444.1 Basic Calibration Blocks. Blocks for pumps and valves shall be in accordance with Appendix J, except that only alternative (c) of Appendix J shall apply.

T-444.2 Examination. Examination shall be made in accordance with T-470, except that T-444.2.1 shall be substituted for T-470.1.1.

T-444.2.1 General. This subparagraph describes the requirements for ultrasonic examination of welds, or base metal repairs, or both, in valves and pumps. Some cast alloys may not be examinable by the techniques given here.

T-444.2.2 Recording. Record reflectors in accordance with T-441.1.7, T-441.1.8, and T-441.1.9.

T-445 Inservice Examination of Bolts and Studs

T-445.1 When inservice examination of bolts and studs is specified by the referencing Code Section, the examination shall be performed in accordance with Appendix L.

T-445.2 For materials with diameters 2 in. (51 mm) and greater, basic calibration blocks shall have reflectors in accordance with Appendix L.

T-445.3 For bolts and studs less than 2 in. in diameter, a calibration block shall be made to the requirements of Appendix L, except for the size of the reflectors. The reflector area shall be established as one thread depth for the threads used on the bolt or stud. The area of the reflector is determined by the depth of a

straight notch and the resulting length of the notch. Any of the types of notches illustrated in Appendix L, Fig. L-13-1 may be used as long as the area does not exceed that calculated for a straight notch one thread depth deep.

T-445.4 Any discontinuity which causes an indication in excess of that produced by the calibration reflector shall be investigated. The shape, identity, and location of all such reflectors shall be evaluated in terms of the acceptance-rejection standards of the referencing Code Section.

T-450 PROCEDURE REQUIREMENTS

Ultrasonic examination shall be performed in accordance with a written procedure. Each procedure shall include the following information with a single value or range of values as applicable:

(a) weld types and configurations to be examined, including thickness dimensions, materials, and product form (casting, forging, plate, etc.);

(b) the surface or surfaces from which the examination shall be performed;

(c) surface condition requirements;

(d) couplant brand name or type;

(e) technique (straight beam, angled beam, contact and/or immersion) used for detection and sizing;

(f) angles and mode(s) of wave propagation in the material;

(g) search unit type, frequency, and transducer size(s) minimum/maximum pulse repetition rate;

(h) special search units, wedges, shoes, or saddles, type, maximum length of search unit cable;

(i) ultrasonic instrument type(s) including manufacturer and model or series of pulser, receiver, and amplifier;

(j) description of calibration blocks and technique(s) for detection and sizing;

(k) beam directions, extent of scanning maximum scan speed, scanning pattern and steps;

(l) minimum data to be recorded and method of recording (manual or automatic) minimum sampling rate for automatic;

(m) automatic alarm and recording equipment, or both (e.g., strip chart, analog tape, digitizing);

(n) rotating, revolving, or scanning mechanisms, if used;

(o) personnel qualification requirements;

(p) describe the demonstration or qualification of the procedure used to detect and size flaws as required by the referencing Code Section;

(q) method and criteria for discriminating geometric from flaw indications;

(r) method and criteria for length and depth sizing of flaws;

(s) minimum calibration data to be recorded;

(t) identification of qualification specimen;

(u) identification of essential variables and range of qualification.

T-460 CALIBRATION

T-461 Instrument Calibration

The requirements of T-461.1 and T-461.2 shall be met at the beginning and end of the weld examinations performed during one outage.

T-461.1 Screen Height Linearity. The ultrasonic instrument shall provide linear vertical presentation within ±5% of the full screen height for at least 80% of the calibrated screen height [base line to maximum calibrated screen point(s)]. The procedure for evaluating screen height linearity is provided in Appendix I and shall be performed at the beginning of each period of extended use (or every 3 months, whichever is less).

T-461.2 Amplitude Control Linearity. The ultrasonic instrument shall utilize an amplitude control, accurate over its useful range to ±20% of the nominal amplitude ratio, to allow measurement of indications beyond the linear range of the vertical display on the screen. The procedure for evaluating amplitude control linearity is given in Appendix II.

T-462 System Calibration (General)

Calibration includes all those actions required to assure that the sensitivity and accuracy of the signal amplitude and time outputs of the examination system (whether displayed, recorded, or automatically processed) are repeated from examination to examination.

Calibration may be by use of basic calibration blocks with artificial or defect reflectors.

Methods are provided in Appendices B and C.

Other methods of calibration may include sensitivity adjustment based on the examination material, etc.

T-470 EXAMINATION

T-471 Examination of Vessel Welds

T-471.1 General. This paragraph describes the requirements for ultrasonic examination of vessel welds

and/or base metal repairs. The requirements described here are used on ferritic materials greater than 2 in. (51 mm) in thickness to detect, locate, and dimension indications within the weld or weld repaired base materials and adjacent base material.

T-471.1.2 Surface Preparation. The examination surfaces shall be free of irregularities, loose foreign matter, or coatings which interfere with ultrasonic wave transmission.

T-471.1.3 Uniform Technique for Identification of Examination Areas

(a) Weld Locations. Weld identification and location shall be shown on a weld identification plan.

(b) Marking. If welds are to be permanently marked, low stress stamps and/or vibratooling may be used. Markings applied after final stress relief of the component shall not be any deeper than $^3/_{64}$ in. (1.2 mm).

(c) Reference System. Each weld and examination area shall be located and identified by a system of reference points. The system shall permit identification of each weld center line and designation of regular intervals along the length of the weld. A general system for layout of vessel welds is described in Appendix A; however, a different system may be utilized provided it meets the above requirements.

T-480 EVALUATION

T-481 General

It is recognized that not all ultrasonic reflectors indicate flaws, since certain metallurgical discontinuities and geometric conditions may produce indications that are not relevant. Included in this category are plate segregates in the heat affected zone that become reflective after fabrication. Under straight beam examination, these may appear as spot or line indications. Under angle beam examination, indications that are determined to originate from surface conditions (such as weld root geometry) or variations in metallurgical structure in stainless steel materials (such as the automatic-to-manual weld clad interface) may be classified as geometric indications. The identity, maximum amplitude, location, and extent of reflector causing a geometric indication shall be recorded. (For example: internal attachment, 200% DAC, 1 in. above weld center line, on the inside surface, from 90 to 95 deg.) The following steps shall be taken to classify an indication as geometric:

(a) interpret the area containing the reflector in accordance with the applicable examination procedure;

(b) plot and verify the reflector coordinates. Prepare a cross-sectional sketch showing the reflector position and surface discontinuities such as root and counterbore; and

(c) review fabrication or weld preparation drawings. Other ultrasonic techniques or nondestructive examination methods may be helpful in determining a reflector's true position, size, and orientation.

T-482 Evaluation of Reflectors

T-482.1 Evaluation of Planar Reflectors

T-482.1.1 Reflectors shall be evaluated in accordance with a qualified procedure.

T-482.2 Evaluation of Laminar Reflectors

T-482.2.1 Evaluation of Laminar Reflectors for Interference With Angle Beam Examinations. Data recorded as required in T-441.1.9(a) and (c) represent the dimensions of the reflector needed to determine interference with angle beam examinations. Where laminar reflectors interfere with the scanning of examination volumes for planar reflectors, the angle beam examination technique shall be modified to examine the maximum feasible volume, within the specified examination volume, and the description of the volume excluded by the lamination shall be noted in the record of the examination [T-492(e)].

T-482.2.2 Evaluation of Laminar Reflectors for Acceptance. Data recorded as required in T-441.1.2.9(b) and (c) represent the dimensions of the reflector.

T-483 Alternative Evaluations

Reflector dimensions exceeding the referencing Code Section requirements may be evaluated to any alternative standards as may be provided by the referencing Code Section.

T-490 RECORDS

T-491 Calibration Records

Instrument calibrations (T-461) shall be included in the ultrasonic calibration records. Ultrasonic examination system calibration requirements and identity of calibration block, if used, shall be included in the ultrasonic calibration records.

T-492 Examination Records

For each ultrasonic examination, the following information shall be identified and recorded:

(a) procedure;

(b) ultrasonic examination system (equipment);

(c) examination personnel identity and level if required by referencing Code Section;

(d) calibration sheet identity;

(e) identification and location of weld or volume scanned;

(f) surface from which examination was conducted;

(g) map or record of indications detected or areas cleared;

(h) date and time examinations were performed;

(i) couplant used, brand name, or type;

(j) identification of basic calibration block (if used);

(k) surface condition;

(l) frequency(ies), and

(m) special equipment.

T-493 Evaluation Record

Records of any evaluations of indications shall be maintained and documented.

T-494 Report

A report of the examinations shall be made. The report shall include a record indicating the weld(s) or volume examined (this may be marked-up drawings or sketches), the location of each recorded reflector, and the identification of the operator who carried out each examination or part thereof as detailed in T-490. The report shall be filed and maintained in accordance with the referencing Code Section.

ARTICLE 4
MANDATORY APPENDICES

APPENDIX I — SCREEN HEIGHT LINEARITY

To verify the ability of the ultrasonic instrument to meet the linearity requirement of T-461.1, position an angle beam search unit as shown in Fig. I-1 so that indications can be observed from both the $\frac{1}{2}$ and $\frac{3}{4}T$ holes in a basic calibration block. Adjust the search unit position to give a 2:1 ratio of amplitudes between the two indications, with the larger set at 80% of full screen height. Without moving the search unit, adjust sensitivity (gain) to successively set the larger indication from 100% to 20% of full screen height, in 10% increments (or 2 dB steps if a fine control is not available), and read the smaller indication at each setting. The reading must be 50% of the larger amplitude, within 5% of full screen height. The settings and readings must be estimated to the nearest 1% of full screen. Alternatively, a straight beam search unit may be used on any calibration block which will provide amplitude differences, with sufficient signal separation to prevent overlapping of the two signals.

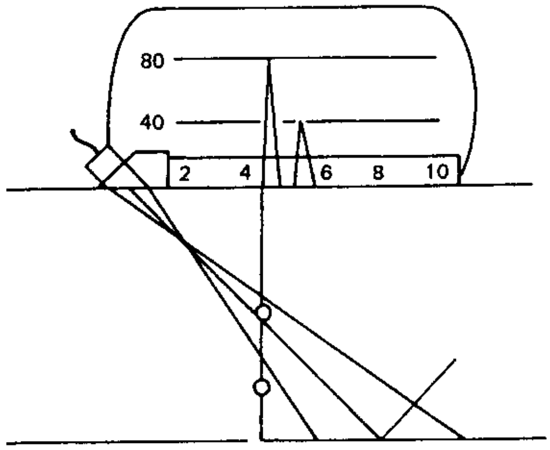


FIG. I-1 LINEARITY

APPENDIX II — AMPLITUDE CONTROL LINEARITY

To verify the accuracy of the amplitude control of the ultrasonic instrument, as required in T-461.2, position an angle beam search unit as shown in Fig. I-1 so that the indication from the $\frac{1}{2}T$ hole in a basic calibration block is peaked on the screen. With the increases and decreases in attenuation shown in the following table, the indication must fall within the specified limits. Other convenient reflectors from any calibration block may be used with angle or straight beam search units.

Indication Set at % of Full Screen	dB Control Change	Indication Limits % of Full Screen
80%	–6 dB	32 to 48%
80%	–12 dB	16 to 24%
40%	+6 dB	64 to 96%
20%	+12 dB	64 to 96%

The settings and readings must be estimated to the nearest 1% of full screen.

ARTICLE 4
NONMANDATORY APPENDICES

APPENDIX A — LAYOUT OF VESSEL REFERENCE POINTS

The layout of the weld shall consist of placing reference points on the center line of the weld. The standard spacing of the reference points shall be 12 in. All points shall be identified with their numbers: 0, 1, 2, 3, 4, etc. The numbers of points, distance apart, and starting point shall be recorded on the reporting form. The weld center line shall be the divider for the two examination surfaces.

(a) Circumferential (Girth) Welds. The standard starting point shall be vessel 0 deg. The reference points shall be numbered clockwise, as viewed from the top of the vessel. The examination surfaces shall be identified as above or below the weld.

(b) Longitudinal (Vertical) Welds. Longitudinal welds shall be laid out from the center line of circumferential welds at the top end of the weld. The examination surface shall be identified as clockwise or counterclockwise as viewed from the top of the vessel.

(c) Nozzle-to-Vessel Welds. The external reference circle shall have a sufficient whole number of inches radius so that the circle falls on vessel external surface beyond the weld fillet. The internal reference circle shall have a sufficient whole number of inches radius so that the circle falls within ½ in. (13 mm) of the weld center line. Zero deg. point on the weld will be the top of the nozzle. The 0 deg. point for welds of nozzles centered in heads shall be located at the 0 deg. axis of the vessel. Angular layout of the weld shall be made clockwise on the external surface, counterclockwise on the internal surface. Zero degree, 90 deg., 180 deg., and 270 deg. lines will be marked on all nozzle welds examined; 30 deg. increment lines will be marked on nozzle welds greater than 4 in. (102 mm) radius; 15 deg. increment lines will be marked on nozzle welds greater than 12 in. (305 mm) radius; 5 deg. increment lines will be marked on nozzle welds greater than 24 in. (610 mm) radius.

APPENDIX B — GENERAL TECHNIQUES FOR ANGLE BEAM CALIBRATIONS

Descriptions and figures for the general method relate position and depth of the reflector to eighths of the V-path. The sweep range may be calibrated in terms of units of metal path,[1] projected surface distance or actual depth to the reflector (as shown in Fig. B-10). The particular method may be selected according to the preference of the examiner.

B-1 GENERAL REQUIREMENTS

Calibration shall include the complete ultrasonic examination system. The original calibration must be performed on the basic calibration block. Checks shall be made to verify the sweep range calibration and distance amplitude correction. Checks shall include the entire examination system.

In all calibrations, it is important that maximum indications be obtained with the sound beam oriented perpendicular to the axis of the side-drilled holes and notches. The center line of the search unit shall be at least 1½ in. (38 mm) from the nearest side of the block (rotation of the beam into the corner formed by the hole and the side of the block may produce a higher amplitude at a longer beam path; this beam path shall not be used for calibration). For contact examination, the temperature of the examination and basic calibration block surfaces shall be within 25°F (14°C). For immersion examination, the couplant temperature for calibration shall be within 25°F (14°C) of the couplant temperature used in actual scanning, or appropriate compensations for angle and sensitivity changes shall be made.

[1] Reflections from concentric cylindrical surfaces such as provided by some IIW blocks and the AWS distance calibration block may be used to adjust delay zero and sweep range for metal path calibration.

B-2 CALIBRATION CHECK UPON CHANGE IN THE COMPLETE ULTRASONIC EXAMINATION SYSTEM

Alternate cables and search units singly and in combination that have been included in a prior system calibration may be later substituted in the system; such substitution shall not necessitate a calibration check. When any other part of the examination system is changed, a calibration check shall be made on the basic calibration block or on the simulator, provided the simulation is subsequently compared to the basic calibration block to verify that $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}T$ points on the sweep and distance amplitude correction values recorded satisfy the requirements of Appendix B-71 and Appendix B-72.

B-3 CALIBRATION CHECK ON BASIC CALIBRATION BLOCK OR SIMILAR CHECK

A calibration check on at least three of the basic reflectors in the basic calibration block or a check on at least three of the simulation reflectors in the simulation block shall be made at the finish of each examination. Interim calibration checks may be made as above or on the three required pulses from the electronic simulator every 12 hr during the examination and when examination personnel (except for mechanized examinations) are changed.

When a simulator is used, a minimum of three pulses shall be used to simulate the original calibration performed on the basic calibration block. The three pulses shall be within the ranges of 15% to 20%, 40% to 60%, and 70% to 110% of the maximum calibrated metal path. Simulator block reflectors and/or electronic simulator settings shall be recorded in the written calibration record. When an electronic simulator is used, it shall be electronically calibrated at least every 6 months to verify compliance with the manufacturer's specification. The sweep and distance–amplitude correction values recorded shall satisfy the requirements of Appendix B-71 and Appendix B-72.

B-4 SIMULATOR CHECK

Any simulator checks that are used must be correlated with the original calibration on the basic calibration block during the original calibration. The simulator checks may use different types of calibration blocks (such as IIW) and/or electronic simulation. However, the simulation used shall be completely identifiable on the calibration sheet(s). The simulator check shall be made on the entire examination system. The entire system does not have to be tested in one check. As an example, the transducer sensitivity and electronic instrument could be evaluated in separate tests.

B-5 CALIBRATION MEASUREMENTS

Each calibration shall be performed from the surface (clad or unclad) corresponding to the surface of the component from which the examination will be performed.

B-6 TECHNIQUES

Appendix B provides general techniques for angle beam calibration. Other techniques may be used. Any control which affects the instrument linearity (e.g., filters, reject, or clipping), shall be in the same position for calibration linearity checks and examination.

B-7 ANGLE BEAM CALIBRATION

The calibration shall provide the following measurements:

(a) sweep range calibration;

(b) distance–amplitude correction;

(c) position calibration;

(d) echo amplitude measurement from the surface notch in the basic calibration block;

(e) when an electronic distance amplitude correction device is used, the primary reference response shall be equalized at a nominal constant screen height at or between 40% to 80% of full screen height over the distance range to be employed in the examination.

B-8 INNER $\frac{1}{4}$ VOLUME

(a) The additional $\frac{1}{4}$ volume angle calibration requirement may be satisfied by using one or more beams as required to calibrate on $\frac{1}{8}$ in. (3.2 mm) maximum diameter side drilled holes in that volume.

(b) When the examination is performed from the outside surface, calibrate on the $\frac{1}{8}$ in. (3.2 mm) diameter side drilled holes to provide the shape of the DAC from $\frac{1}{2}$ in. (13 mm) to $\frac{1}{4}$ depth, but set gain on the Code hole at $\frac{1}{4}$.

(c) When the examination is performed from the inside surface, calibrate on the $\frac{1}{8}$ in. (3.2 mm) diameter

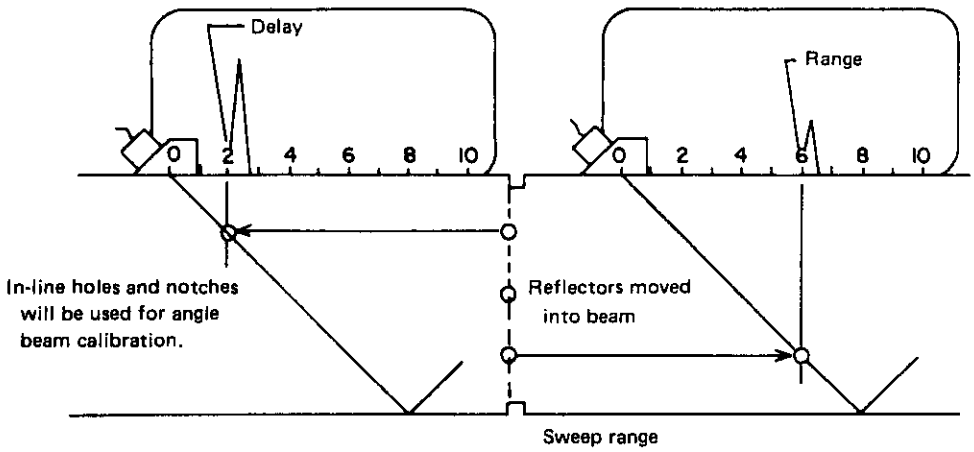


FIG. B-10 SWEEP RANGE

side drilled holes to provide the shape of the DAC and the gain setting.

B-10 SWEEP RANGE CALIBRATION (SEE FIG. B-10)

(a) Position the search unit for the maximum first indication from the $\frac{1}{4}T$ side-drilled hole. Adjust the left edge of this indication to line 2 on the screen with the delay control.

(b) Position the search unit for the maximum indication from the $\frac{3}{4}T$ hole. Adjust the left edge of this indication to line 6 on the screen with the range control.

(c) Repeat delay and range control adjustments until the $\frac{1}{4}T$ and $\frac{3}{4}T$ hole reflections start at sweep lines 2 and 6.

(d) Position the search unit for maximum response from the square notch on the opposite surface. The indication will appear near sweep line 8.

(e) Two divisions on the sweep equal $\frac{1}{4}T$.

B-20 DISTANCE–AMPLITUDE CORRECTION (PRIMARY REFERENCE LEVEL) (SEE FIG. B-20)

B-21 Calibration From the Clad Side

(a) Position the search unit for maximum response from the hole which gives the highest amplitude.

(b) Adjust the sensitivity control to provide an 80% (±5% of full screen height) of full screen indication from the hole. Mark the peak of the indication on the screen.

(c) Position the search unit for maximum response from another hole indication.

(d) Mark the peak of the indication on the screen.

(e) Position the search unit for maximum amplitude from the third hole indication and mark the peak on the screen.

(f) Position the search unit for maximum amplitude from the $\frac{3}{4}T$ hole indication after the beam has bounced from the opposite surface. The indication should appear at sweep line 10. Mark the peak on the screen for the $\frac{5}{4}T$ position.

(g) Connect the screen marks for the side-drilled holes to provide the distance–amplitude curve.

(h) For calibration correction for perpendicular reflectors at the opposite surface, refer to B-50.

B-22 Calibration From the Unclad Side

(a) From the clad side of the block, determine the dB change in amplitude between the $\frac{3}{4}T$ and $\frac{5}{4}T$ positions.

(b) From the unclad side, perform calibrations as noted in B-21 (a) through (e).

(c) To determine the amplitude for the $\frac{5}{4}T$ hole, position the search unit for maximum amplitude from the $\frac{3}{4}T$ hole. Decrease the signal amplitude by the number of dB determined in (a) above. Mark the height of this signal amplitude at sweep line 10 ($\frac{5}{4}T$).

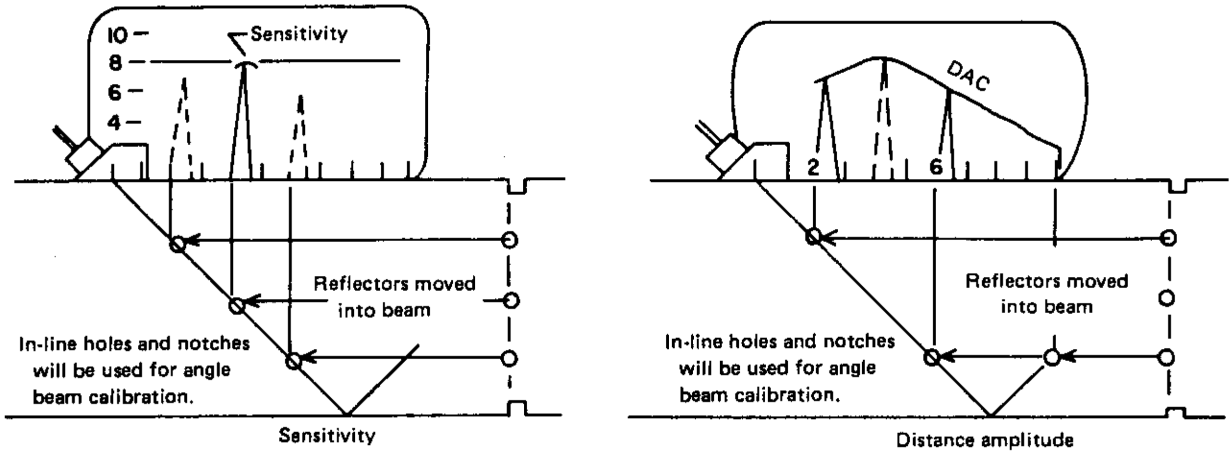


FIG. B-20 SENSITIVITY AND DISTANCE–AMPLITUDE CORRECTION

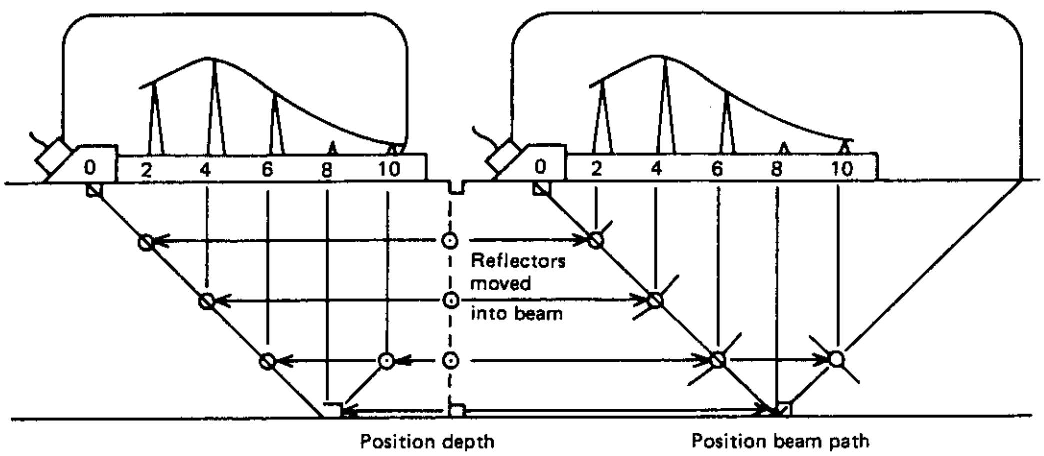


FIG. B-40 POSITION DEPTH AND BEAM PATH

(d) Connect the screen marks to provide the distance-amplitude curve. This will permit evaluation of indications down to the clad surface (near sweep line 8).

(e) For calibration correction for perpendicular planar reflectors near the opposite surface, refer to B-50.

B-40 POSITION CALIBRATION (SEE FIG. B-40)

The following measurements may be made with a ruler, scale, or marked on an indexing strip.[2]

(a) Position the search unit for maximum response from the $\frac{1}{4}T$ hole. Place one end of the indexing strip against the front of the search unit, the other end extending in the direction of the beam. Mark the number 2 on the indexing strip at the scribe line which is directly above the hole. (If the search unit covers the scribe line, the marks may be made on the side of the search unit.)

(b) Position the search unit for maximum indications from the $\frac{1}{2}T$ and $\frac{3}{4}T$ holes. Keep the same end of the indexing strip against the front of the search unit. Mark the numbers 4 and 6 on the indexing strip at the scribe line.

(c) If possible, position the search unit so that the beam bounces from the opposite surface to the $\frac{3}{4}T$ hole. Mark the number 10 on the indexing strip at the scribe line.

(d) Position the search unit for the maximum opposite surface notch indication. Mark the number 8 on the indexing strip at the scribe line.

(e) The calibration numbers on the indexing strip indicate the position directly over the reflector in sixteenths of the V-path.

(f) The depth from the examination surface to the reflector is T at 8, $\frac{3}{4}T$ at 6 and 10, $\frac{1}{2}T$ at 4, $\frac{1}{4}T$ at 2, and 0 at 0. Interpolation is possible for smaller increments of depth. This measurement may be corrected by the radius of the hole if the radius is considered significant to the accuracy of reflector's location.

[2] The balance of the calibrations in this Appendix is written based upon the use of the indexing strip. However, the procedures may be transformed for other methods of measurement at the discretion of the examiner.

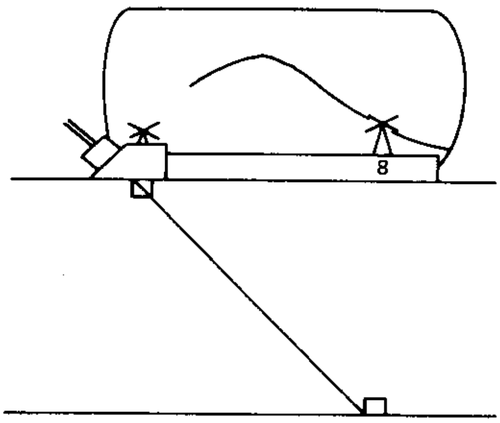


FIG. B-50 PLANAR REFLECTIONS

B-50 CALIBRATION CORRECTION FOR PLANAR REFLECTORS PERPENDICULAR TO THE EXAMINATION SURFACE AT OR NEAR THE OPPOSITE SURFACE (SEE FIG. B-50)

The 45 deg. angle beam shear wave reflects well from a corner reflector. However, mode conversion and redirection of reflection occurs to part of the beam when a 60 deg. angle beam shear wave hits the same reflector. This problem also exists to a lesser degree throughout the 50 deg. to 70 deg. angle beam shear wave range. This correction is required in order to be equally critical of such an imperfection regardless of the examination beam angle.

(a) Position the search unit for maximum amplitude from the square notch on the opposite surface. "X" mark the peak of the indication on the screen near sweep line 8.

(b) The opposite surface square notch may give an indication 2 to 1 above DAC at 45 deg. and $\frac{1}{2}$ DAC at 60 deg. Therefore, the indications from the square notch must be considered when evaluating reflectors at the opposite surface.

B-60 BEAM SPREAD (SEE FIG. B-60)

Measurements of beam spread shall be made on the hemispherical bottom of the round bottom hole. The half maximum amplitude limit of the primary lobe of the beam shall be plotted by manipulating the search unit for measurements on reflections from the round bottom holes as follows.

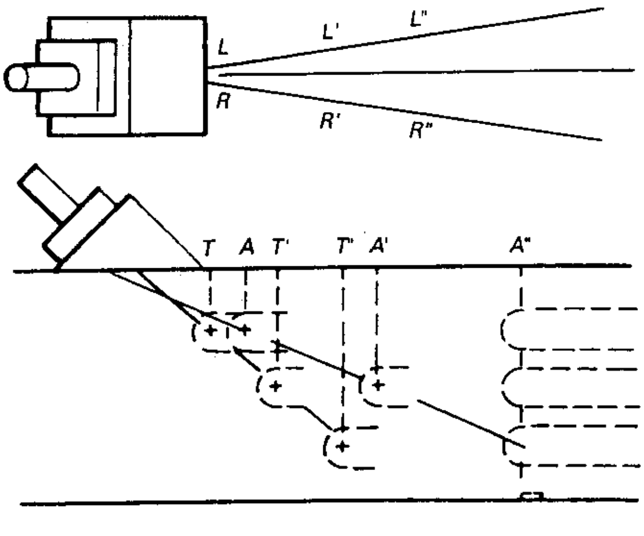


FIG. B-60 BEAM SPREAD

(a) Set the maximum amplitude from the $\frac{1}{4}T$ hole at 80% of full screen. Move search unit toward the hole until indication equals 40% of full screen. Mark beam center line "toward" position on the block.

(b) Set the maximum amplitude from the $\frac{1}{4}T$ hole at 80% of full screen. Move search unit away from the hole until indication equals 40% of full screen. Mark beam center line "away" position on the block.

(c) Position the search unit for 80% of roll screen amplitude from the $\frac{1}{4}T$ hole. Move search unit right without pivoting the beam toward the reflector until the indication equals 40% of full screen. Mark the beam center line "right" position on the block.[3]

(d) Move the search unit left without pivoting the beam toward the reflector until the indication equals 40% of full screen. Mark the beam center line "left" position on the block.[3]

(e) Repeat setting and measurements of "toward," "away," "right," and "left" limits of the beam on the $\frac{1}{2}T$ and $\frac{3}{4}T$ round bottom holes.

(f) Record the dimensions from "toward" to "away" and from "right" to "left" positions marked on the block for the $\frac{1}{4}T$ and $\frac{3}{4}T$ round bottom holes.

(g) The smallest of the three "toward" to "away" dimensions shall not be exceeded when indexing between scans perpendicular to the beam direction.

[3] When manually positioning the search unit, a straight edge may be used to guide the search unit while moving to the right and left to assure that axial positioning and beam alignment are maintained.

(h) The smallest of the three "right" to "left" dimensions shall not be exceeded when indexing between scans parallel to the beam direction.

(i) The projected beam spread angle determined by these measurements shall be used to determine limits as required at other metal paths.

NOTE: If laminar reflectors are present in the basic calibration block, the beam spread readings may be affected; if this is the case, beam spread measurements must be based on the best available readings.

B-70 CALIBRATION CONFIRMATION

Calibration shall be performed prior to use of the system in the thickness range under examination. A calibration check shall verify the sweep range and distance amplitude correction as defined in B-71 and B-72.

B-71 Sweep Range Calibration

If any point on the DAC curve has moved on the sweep line more than 10% of the sweep division reading, correct the sweep range calibration and note the correction in the examination record. If recordable reflectors (T-458) are noted on the data sheets, those data sheets shall be voided, a new calibration shall be recorded, and the voided examinations shall be repeated.

B-72 DAC Correction

If any point on the distance-amplitude correction (DAC) curve has decreased 20% or 2 dB of its amplitude, all data sheets since the last calibration or calibration check shall be marked void. A new calibration shall be made and recorded and the voided examination areas shall be reexamined. If any point on the distance-amplitude correction (DAC) curve has increased more than 20% or 2 dB of its amplitude, all recorded indications since the last valid calibration or calibration check shall be evaluated with the corrected calibration, and their values shall be changed on the data sheets.

APPENDIX C — GENERAL TECHNIQUES FOR STRAIGHT BEAM CALIBRATIONS

C-1 GENERAL REQUIREMENTS

Calibration shall include the complete ultrasonic examination system. The original calibration must be performed on the basic calibration block. Checks shall be made to verify the sweep range calibration and

distance amplitude correction. Checks shall include the entire examination system.

In all calibrations, it is important that maximum indications be obtained with the sound beam oriented perpendicular to the axis of the side-drilled holes and notches. The center line of the search unit shall be at least $1\frac{1}{2}$in. (38 mm) from the nearest side of the block (rotation of the beam into the corner formed by the hole and the side of the block may produce a higher amplitude at a longer beam path; this beam path shall not be used for calibration). For contact examination, the temperature of the examination and basic calibration block surfaces shall be within 25°F (14°C). For immersion examination, the couplant temperature for calibration shall be with 25°F (14°C) of the couplant temperature used in actual scanning, or appropriate compensations for angle and sensitivity changes shall be made.

C-2 CALIBRATION CHECK UPON CHANGE IN THE COMPLETE ULTRASONIC EXAMINATION SYSTEM

Alternate cables and search units singly and in combination that have been included in a prior system calibration may be later substituted in the system: such substitution shall not necessitate a calibration check. When any other part of the examination system is changed, a calibration check shall be made on the basic calibration block to verify that $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}T$ points on the sweep and distance amplitude correction values recorded satisfy the requirements of Appendix C-31 and Appendix C-32.

C-3 CALIBRATION CHECK ON BASIC CALIBRATION BLOCK OR SIMULATOR CHECK

A calibration check on at least three of the basic reflectors in the basic calibration block or a check on at least three of the simulation reflectors in the simulation block shall be made at the finish of each examination. Interim calibration checks may be made as above or on the three required pulses from the electronic simulator every 12 hr during the examination and when examination personnel (except for mechanized examinations) are changed.

When a simulator is used, a minimum of three pulses shall be used to simulate the original calibration performed on the basic calibration block. The three uses shall be within the ranges of 15 to 20%, 40 to 60%, and 70 to 110% of the maximum calibrated metal path. Simulator block reflectors and/or electronic simulator settings shall be recorded in the written calibration record. When an electronic simulator is used, it shall be electronically calibrated at least every 6 months to verify compliance with the manufacturer's specification. The sweep and distance–amplitude correction values recorded satisfy the requirements of Appendix C-31 and Appendix C-32.

C-4 SIMULATOR CHECK

Any simulator checks that are used must be correlated with the original calibration on the basic calibration block during the original calibration. The simulator checks may use different types of calibration blocks (such as IIW) and/or electronic simulation. However, the simulation used shall be completely identifiable on the calibration sheet(s). The simulator check shall be made on the entire examination system. The entire system does not have to be tested in one check. As an example, the transducer sensitivity and electronic instrument could be evaluated in separate tests.

C-5 CALIBRATION MEASUREMENTS

Each calibration shall be performed from the surface (clad or unclad) corresponding to the surface of the component from which the examination will be performed.

C-6 TECHNIQUES

This Appendix provides general techniques for straight-beam calibration. Other techniques may be used. Any control which affects the instrument linearity (e.g., filters, reject, or clipping) shall be in the same position for calibration, linearity check, and examination.

C-7 STRAIGHT BEAM CALIBRATION

The method of calibration shall provide the following measurements (Appendix C gives a general technique):

(a) sweep range calibration;

(b) distance–amplitude correction;

(c) when an electronic distance amplitude correction device is used, the primary reference response shall be equalized at a nominal constant screen height at or between 40% to 80% of full screen height over the distance range to be employed in the examination.

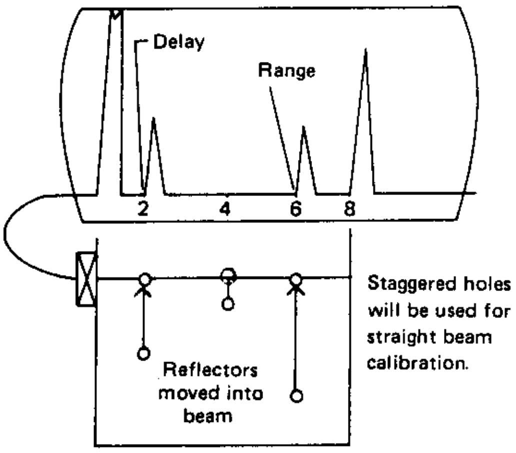


FIG. C-10 SWEEP RANGE

C-10 SWEEP RANGE CALIBRATION[4] (SEE FIG. C-10)

(a) Position the search unit for the maximum first indication from the $\frac{1}{4}T$ side-drilled hole. Adjust the left edge of this indication to line 2 on the screen with the delay control.

(b) Position the search unit for the maximum indication from $\frac{3}{4}T$ hole. Adjust the left edge of this indication to line 6 on the screen with the range control.

(c) Repeat delay and range control adjustments until the $\frac{1}{4}T$ and $\frac{3}{4}T$ hole reflections start at sweep lines 2 and 6.

C-20 DISTANCE–AMPLITUDE CORRECTION (SEE FIG. C-20)

(a) Position for maximum response from the hole which gives the highest amplitude.

(b) Adjust the sensitivity control to provide an 80% (±5% of full screen height) of full screen indication from the hole. Mark the peak of the indication on the screen with a grease pencil or other suitable marker.

(c) Position the search unit for maximum response from another hole indication.

(d) Mark the peak of the indication on the screen.

(e) Position the search unit for maximum amplitude from the third hole indication and mark the peak on the screen.

(f) Connect the screen marks and extend through the thickness to provide the distance–amplitude curve for the side-drilled holes.

C-30 CALIBRATION CONFIRMATION

Calibration shall be performed prior to use of the system in the thickness range under examination. A calibration check shall verify the sweep range and distance amplitude correction as defined in C-31 and C-32.

C-31 Sweep Range Calibration

If any point on the DAC curve has moved on the sweep line more than 10% of the sweep division reading, correct the sweep range calibration and note the correction in the examination record. If recordable reflectors (T-480) are noted on the data sheets, those data sheets shall be voided, a new calibration shall be recorded, and voided examinations shall be repeated.

C-32 DAC Correction

If any point on the distance–amplitude correction (DAC) curve has decreased 20% or 2 dB of its amplitude, all data sheets since the last calibration or calibration check shall be marked void. A new calibration shall be made and recorded and the voided examination areas shall be reexamined. If any point on the distance-amplitude correction (DAC) curve has increased more than 20% or 2 dB of its amplitude, all recorded indications since the last valid calibration or calibration check shall be evaluated with the corrected calibration and their values shall be changed on the data sheets.

APPENDIX D — DATA RECORD EXAMPLE FOR A PLANAR REFLECTOR

D-10 RECORDING DATA (SEE FIG. D-10)

This Appendix represents an example of the data required to dimension a 120% DAC reflector found when scanning perpendicular to a weld. Figure D-10 is an illustration of the maximum amplitude scan and

[4] Calibration by beam path measurement may be used by range control positioning by the block back reflection to the sweep division number (or multiple) equal to the measured thickness. The $\frac{1}{4}T$ hole indication must be delay control positioned to $\frac{1}{4}$ of the sweep division number.

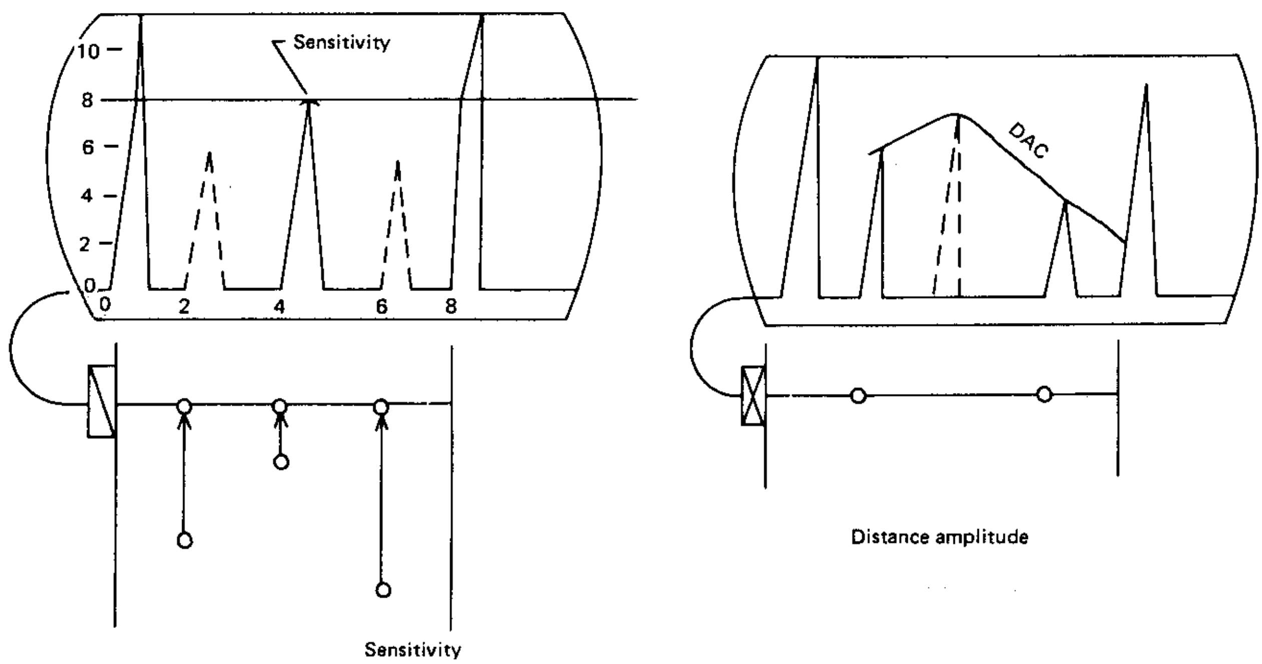


FIG. C-20 SENSITIVITY AND DISTANCE–AMPLITUDE CORRECTION

tabulation of that data with additional scan data that might be taken on the reflector.

(a) Position the search unit to give the maximum amplitude from the reflector. Read and record the *maximum* amplitude in percent of DAC.

(b) Read and record the sweep reading to reflector (at the left side of the indication on the sweep).

(c) Read and record the *position* of the search unit with respect to the reference line.

(d) Read and record the *location* of the indication at the beam center line intersection with reference line from the weld layout reference points.

Move the search unit toward the reflector until the amplitude falls to 60% DAC (half maximum amplitude). Read and record the

(e) minimum sweep reading and

(f) minimum position

Move the search unit away from the reflector past the maximum amplitude position until the amplitude falls to 60% DAC (half maximum amplitude). Read and record the

(g) maximum sweep reading and

(h) maximum position

Data points (a) through (h) above shall be read and recorded during the examination. Computations for (i) depth, (j) distance from surface, and length of the reflector shall be made prior to completion of the examination report.

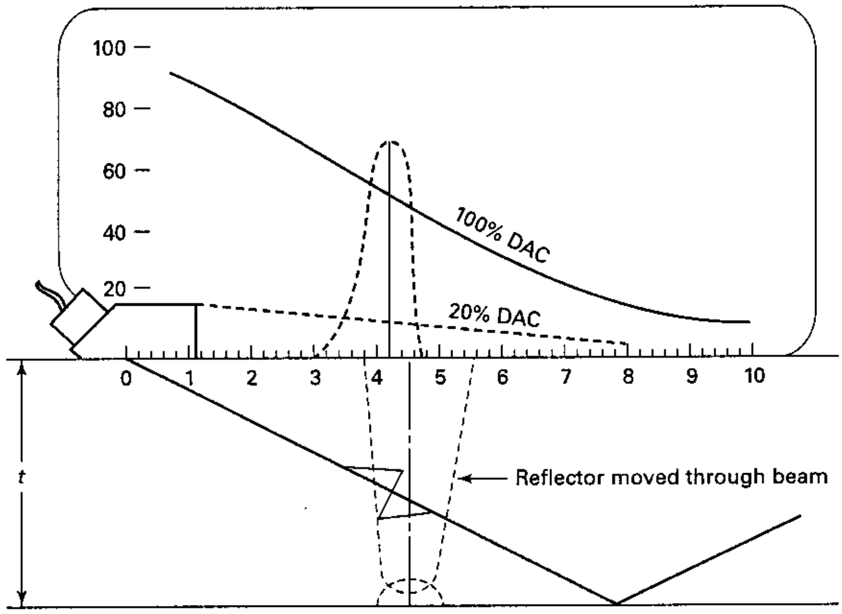
Subtract the minimum sweep reading from the maximum sweep reading and divide by the sweep reading for one wall thickness and multiply by 100 and record as

(i) depth in % of t (t = weld thickness)

Subtract the maximum sweep reading from the sweep reading for one wall thickness or use the minimum sweep reading, whichever gives the smaller number, and divide the number by the sweep reading for one wall thickness. Multiply by 100 and record as

(j) distance from surface in % of t and length of reflection.

Successively read and record data along scan paths at increments no greater than nine-tenths of the transducer (measured parallel to the scan increment change) at 60% DAC (half maximum amplitude). Continue scans until the maximum amplitude found at the end points of the reflector is 20% DAC. The length of the reflector is the distance between the end points measured at the reflector in inches. The length shall be divided by t and multiplied by 100 to give length in % of t. The data tabulated in Fig. D-10 is carried out on either side of the maximum indicated signal until the 20% DAC point is reached on both ends of the indication. It is only necessary to record the data to obtain the



GENERAL NOTE: As the reflector is moved through the beam, the flaw indication reaches 20% DAC at 4.4 sweep divisions, increases in amplitude to 120% DAC at 4.0 sweep divisions, and falls to 20% DAC at 3.6 sweep divisions. The 20% DAC change in sweep reading, divided by the thickness sweep reading, times 100 represents the reflector depth (that is, 10% of t) or the 2 (a) dimension of the subsurface flaw indication.

FIG. D-10 REFLECTOR READING

DATA TABULATION FOR FIG. D-10

(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	
				20% DAC				% of t		
				Minimum		Maximum				
Maximum % DAC	Sweep Reading	Search Unit Position, in. or mm	Location, in. or mm	Sweep Reading	Position	Sweep Reading	Position	Depth	Distance From Surface	Computation or Remarks
120	4.0	4.6	23	3.6	4.2	4.4	5.2	10	45	$\frac{4.4-3.6}{8.0}$
80	4.0	4.6	22.1	3.8	4.3	4.2	4.8	5	47.5	$\frac{4.2-3.8}{8.0}$
20	4.0	4.6	21.7	...	...	...	...	0	50	...
90	4.1	4.7	23.9	3.7	4.3	4.3	5.2	7.5	46	$\frac{4.3-3.7}{8.0}$
70	4.1	4.7	24.8	3.9	4.4	4.3	5.2	5	46	$\frac{4.3-3.9}{8.0}$
20	4.2	4.6	25	...	...	...	...	0	50	...
										depth: 10% of t
										length: 3.3 in. or mm

GENERAL NOTE:
Column letters refer to D-10 subparagraphs.

length 3.3 in. (84 mm) and depth, 10% of t. The first, third, and sixth lines of the data tabulation are all that are necessary to define the through wall and length of the indication in this example.

APPENDIX E — COMPUTERIZED IMAGING TECHNIQUES

E-10 GENERAL REQUIREMENTS

Computerized imaging techniques (CITs) shall satisfy all of the basic instrument requirements described in T-431 and T-461. The search units used for CIT applications shall be characterized as specified in T-434. CITs shall be qualified in accordance with the requirements for flaw detection and/or sizing that are specified in the referencing Code Section.

The written procedure for CIT applications shall identify the specific test frequency and bandwidth to be utilized. In addition, such procedures shall define the signal processing techniques, shall include explicit guidelines for image interpretation, and shall identify the software code/program version to be used. This information shall also be included in the examination report. Each examination report shall document the specific scanning and imaging processes that were used so that these functions may be accurately repeated at a later time if necessary.

The computerized imaging process shall include a feature that generates a dimensional scale (in either two or three dimensions, as appropriate) to assist the operator in relating the imaged features to the actual, relevant dimensions of the component being examined. In addition, automated scaling factor indicators shall be integrally included to relate colors and/or image intensity to the relevant variable (i.e., signal amplitude, attenuation, etc.).

E-20 CALIBRATION

Calibration of computer imaging systems shall be conducted in such a manner that the gain levels are optimized for data acquisition and imaging purposes. The traditional DAC-based calibration process may also be required to establish specific scanning and/or flaw detection sensitivity levels.

For those CITs that employ signal processing to achieve image enhancement (SAFT-UT, L-SAFT, and broadband holography), at least one special lateral resolution and depth discrimination block for each specified examination shall be used in addition to the applicable calibration block required by Article 4. These blocks shall comply with J-10.

The block described in Fig. E-10 provides an effective resolution range for 45 deg. and 60 deg. search units and metal paths up to about 4 in. (102 mm). This is adequate for piping and similar components, but longer path lengths are required for reactor pressure vessels. A thicker block with the same sizes of flat-bottom holes, spacings, depths, and tolerances is required for metal paths greater than 4 in. (102 mm), and a 4 in. (102 mm) minimum distance between the edge of the holes and the edge of the block is required. These blocks provide a means for determining lateral resolution and depth discrimination of an ultrasonic imaging system.

Lateral resolution is defined as the minimum spacing between holes that can be resolved by the system. The holes are spaced such that the maximum separation between adjacent edges of successive holes is 1.000 in. (25.400 mm). The spacing progressively decreases by a factor of two between successive pairs of holes, and the minimum spacing is 0.015 in. (0.381 mm). Depth discrimination is demonstrated by observing the displayed metal paths (or the depths) of the various holes. Because the hole faces are not parallel to the scanning surface, each hole displays a range [about 0.1 in. (2.54 mm)] of metal paths. The "A" row has the shortest average metal path, the "C" row has the longest average metal path, and the "B" holes vary in average metal path.

Additional blocks are required to verify lateral resolution and depth discrimination when 0 deg. longitudinal-wave examination is performed. Metal path lengths of 2 in. and 8 in. (51 mm and 203 mm), as appropriate, shall be provided as shown in Fig. E-20 for section thicknesses to 4 in. (102 mm), and a similar block with 8 in. (203 mm) metal paths is needed for section thicknesses over 4 in. (102 mm).

E-30 SYNTHETIC APERTURE FOCUSING TECHNIQUE FOR ULTRASONIC TESTING (SAFT-UT)

The Synthetic Aperture Focusing Technique (SAFT) refers to a process in which the focal properties of a large-aperture focused search unit are synthetically generated from data collected while scanning over a large area using a small search unit with a divergent sound beam. The processing required to focus this collection of data is a three-dimensional process called beam-forming, coherent summation, or synthetic aperture processing. The SAFT-UT process offers aninherent

advantage over physical focusing processes because the resulting image is a full-volume, focused characterization of the material volume being examined. Traditional physical focusing processes provide focused data over only the depth of the focus zone of the transducer.

For the typical pulse-echo data collection scheme used with SAFT-UT, a focused search unit is positioned with the focal point located at the surface of the material under examination. This configuration produces a divergent ultrasonic beam in the material. Alternatively, a small-diameter contact search unit may be used to generate a divergent beam. As the search unit is scanned over the surface of the material, the A-scan record (RF waveform) is digitized for each position of the search unit. Any reflector present produces a collection of echoes in the A-scan records. For an elementary single-point reflector, the collection of echoes will form a hyperbolic surface within the data-set volume. The shape of the hyperboloid is determined by the depth of the reflector and the velocity of sound in the material. The relationship between echo location in the series of A-scans and the actual location of reflectors within the material makes it possible to reconstruct a high-resolution image that has a high signal-to-noise ratio. Two separate SAFT-UT configurations are possible: (a) the single-transducer, pulse-echo configuration; and (b) the dual-transducer, tandem configuration (TSAFT).

In general, the detected flaws may be categorized as volumetric, planar, or cracks. Flaw sizing is normally performed by measuring the vertical extent (cracks) or the cross-sectional distance (volumetric/planar) at the −6 dB levels once the flaw has been isolated and the image normalized to the maximum value of the flaw. Multiple images are often required to adequately categorize (classify) the flaw and to characterize the actual flaw shape and size. Tandem sizing and analysis uses similar techniques to pulse-echo, but provides images that may be easier to interpret.

The location of indications within the image space is influenced by material thickness, velocity, and refracted angle of the UT beam. The SAFT algorithm assumes isotropic and homogeneous material; i.e., the SAFT algorithm requires (for optimum performance) that the acoustic velocity be accurately known and constant throughout the material volume.

Lateral resolution is the ability of the SAFT-UT system to distinguish between two objects in an xy plane that is perpendicular to the axis of the sound beam. Lateral resolution is measured by determining the minimum spacing between pairs of holes that are clearly separated in the image. A pair of holes is considered separated if the signal amplitude in the image decreases by at least 6 dB between the peak signals of two holes.

Depth resolution is the ability of a SAFT-UT system to distinguish between the depth of two holes whose axes are parallel to the major axis of the sound beam. Depth resolution is measured by determining the minimum difference in depth between two holes.

The lateral resolution for a SAFT-UT system is typically 1.5 wavelengths (or better) for examination of wrought ferritic components, and 2.0 wavelengths (or better) for examination of wrought stainless steel components. The depth resolution for these same materials will typically be 0.25 wavelengths (or better).

E-40 LINE-SYNTHETIC APERTURE FOCUSING TECHNIQUE (L-SAFT)

The Line Synthetic Aperture Focusing Technique (L-SAFT) is useful for analyzing detected indications. L-SAFT is a two-dimensional process in which the focal properties of a large-aperture, linearly focused search unit are synthetically generated from data collected over a scan line using a small search unit with a diverging sound beam. The processing required to impose a focusing effect of the acquired data is also called synthetic aperture processing. The L-SAFT system can be operated like conventional UT equipment for data recording. It will function with either single- or dual-element transducers.

Analysis measurements, in general, are performed to determine flaw size, volume, location, and configuration. To decide if the flaw is a crack or volumetric, the crack-tip-diffraction response offers one criterion, and the superimposed image of two measurements made using different directions of incidence offers another.

All constraints for SAFT-UT apply to L-SAFT and vice versa. The difference between L-SAFT and SAFT-UT is that SAFT-UT provides a higher resolution image than can be obtained with L-SAFT.

E-50 BROADBAND HOLOGRAPHY TECHNIQUE

The holography technique produces an object image by calculation based on data from a diffraction pattern. If the result is a two-dimensional image and the data are acquired along one scan, the process is called "line-holography." If the result is a two-dimensional image based upon an area scanned, then it is called "holography." For the special case of applying holography principles to ultrasonic testing, the image of flaws (in more than one dimension) can be obtained by recording

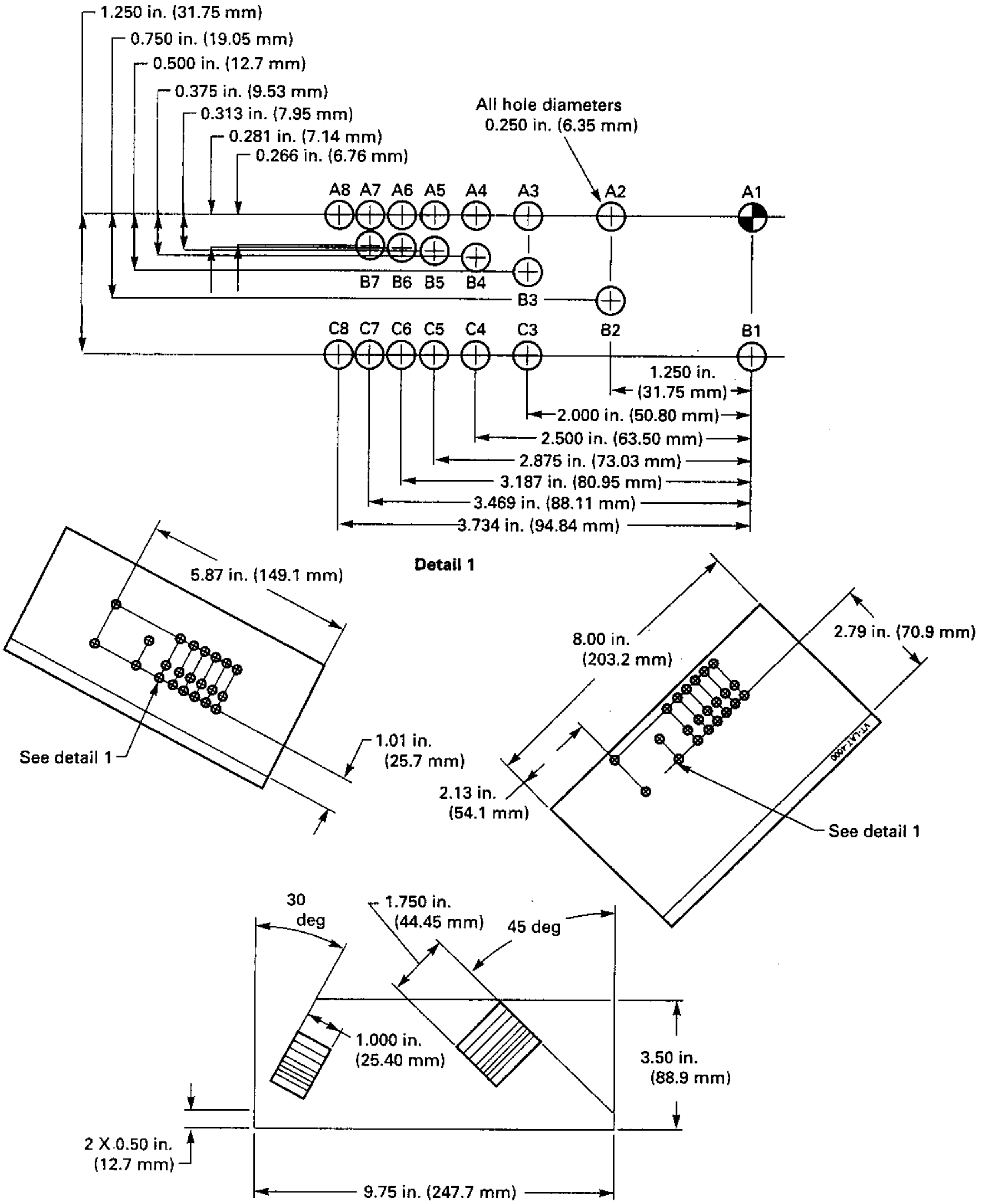


FIG. E-10 LATERAL RESOLUTION AND DEPTH DISCRIMINATION BLOCK FOR 45 deg. AND 60 deg. APPLICATIONS
(Not to Scale)

GENERAL NOTES:
(a) View rotated for clarity.
(b) Insonification surface is shown at bottom.
(c) Tolerances: decimals: 0.XX = ± 0.03; 0.XXX = ± 0.005; angular: ± 1 deg.
(d) Hole identification:
  (1) Engrave or stamp as shown with the characters upright when he large face of the block is up.
  (2) Nominal character height is 0.25 in. (6.4 mm)
  (3) Start numbering at the widest-spaced side.
  (4) Label row of eight holes A1–A8.
  (5) Label diagonal set of seven holes B1–B7.
  (6) Label remaining six holes C3–C8.
(e) Hole spacing: minimum 0.010 in. (0.25 mm) material between hole edges.
(f) Hole depths: 30 deg. face: 1.000 in. (25.40 mm); 45 deg. face: 1.750 in.
(g) Drawing presentation: holes are shown from drilled face of block.
(h) Hole ends to be flat and parallel to drilled surface within 0.001 in. (0.03 mm) across face of hole.
(i) Maximum radius between side and face of hole is 0.005 in. (0.13 mm)

FIG. E-10 LATERAL RESOLUTION AND DEPTH DISCRIMINATION BLOCK FOR 45 deg. AND 60 deg. APPLICATIONS (CONT'D)

the amplitude, phase, and time-of-flight data from the scanned volume. The holography process offers a unique feature because the resulting image is a one- or two-dimensional characterization of the material.

This technique provides good resolution in the axial direction by using broadband search units. These search units transmit a very short pulse, and therefore the axial resolution is improved. The maximum bandwidth may be 20 MHz without using filtering, and up to 8 MHz using an integrated filter.

Analysis measurements, in general, are performed to obtain information on size, volume, location, and configuration of detected flaws. The results of the holography-measurements per scan line show a two-dimensional image of the flaw by color-coded display. The size of flaws can be determined by using the 6 dB drop in the color code. More information on the flaw dimensions is obtained by scans in different directions (i.e., parallel, perpendicular) at different angles of incidence. To decide if the flaw is a crack or a volumetric flaw, the crack tip technique offers one criterion and comparison of two measurements from different directions of incidence offers another. Measurement results obtained by imaging techniques always require specific interpretation. Small variations in material thickness, sound velocity, or refracted beam angle may influence the reconstruction results. The holography processing calculations also assume that the velocity is accurately known and constant throughout the material.

E-60 UT-PHASED ARRAY TECHNIQUE

The UT-Phased Array Technique is a process wherein UT data are generated by controlled incremental variation of the ultrasonic beam angle in the azimuthal or lateral direction while scanning the object under examination. This process offers an advantage over processes using conventional probes with fixed beam angles because it acquires considerably more information about the reflecting object by using more aspect angles in direct impingement.

Each phased array probe consists of a series of individually wired transducer elements on a wedge that are activated separately using a pre-selectable time delay pattern. With a linear delay time between the transmitter pulses, an inclined sound field is generated. Varying the angle of refraction requires a variation of the linear distribution of the delay time. Depending on the probe design, it is possible to electronically vary either the angle of incidence or the lateral/skew angle. In the receiving mode, acoustic energy is received by the elements and the signals undergo a summation process utilizing the same time delay pattern as was used during transmission.

Flaw sizing is normally performed by measuring the vertical extent (in the case of cracks) or the cross-sectional distance (in the case of volumetric/planar flaws) at the 6 dB levels once the flaw has been isolated and the image normalized. Tandem sizing and analysis uses techniques similar to pulse-echo but provides images that are easier to interpret since specular reflection is used for defects oriented perpendicular to the surface. For cracks and planar defects, the result should be verified using crack-tip-diffraction signals from the upper and lower ends of the flaw, since the phased array approach with tomographic reconstruction is most sensitive to flaw tip indications and is able to give a clear reconstruction image of these refraction

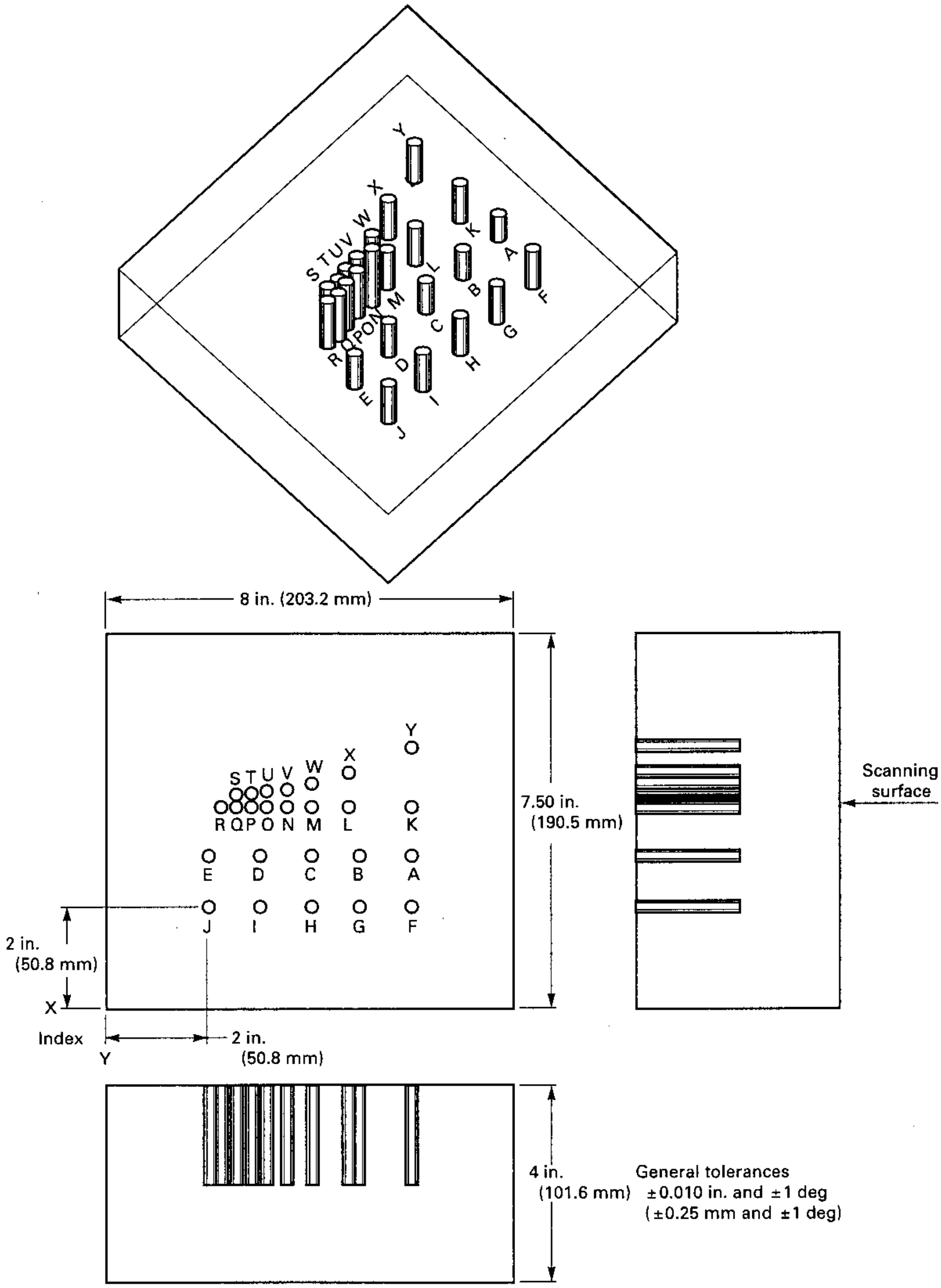


FIG. E-20 LATERAL AND DEPTH RESOLUTION BLOCK FOR 0 deg. APPLICATIONS

TABLE E-20
HOLE PATTERN DIMENSIONS
FOR CALIBRATION BLOCK

	Hole Position X, ±0.005 in. (±0.13 mm)	Hole Position Y, ±0.005 in. (±0.13 mm)	Hole Depth, ±0.002 in. (±0.05 mm)
A	6.000 (152.40)	3.000 (76.20)	1.080 (27.43)
B	5.000 (127.00)	3.000 (76.20)	1.310 (33.27)
C	4.000 (101.60)	3.000 (76.20)	1.540 (39.12)
D	3.000 (76.20)	3.000 (76.20)	1.770 (44.96)
E	2.000 (50.80)	3.000 (76.20)	2.000 (50.80)
F	6.000 (152.40)	2.000 (50.80)	1.828 (46.43)
G	5.000 (127.00)	2.000 (50.80)	1.885 (47.88)
H	4.000 (101.60)	2.000 (50.80)	1.943 (49.35)
I	3.000 (76.20)	2.000 (50.80)	1.977 (50.22)
J	2.000 (50.80)	2.000 (50.80)	2.000 (50.80)
	Hole Position X, ±0.002 in. (±0.05 mm)	**Hole Position Y, ±0.002 in. (±0.05 mm)**	**Hole Depth, ±0.005 in. (±0.13 mm)**
K	6.000 (152.40)	4.000 (101.60)	2.000 (50.80)
L	4.750 (120.65)	4.000 (101.60)	2.000 (50.80)
M	4.000 (101.60)	4.000 (101.60)	2.000 (50.80)
N	3.500 (88.90)	4.000 (101.60)	2.000 (50.80)
O	3.125 (79.38)	4.000 (101.60)	2.000 (50.80)
P	2.813 (71.45)	4.000 (101.60)	2.000 (50.80)
Q	2.532 (64.31)	4.000 (101.60)	2.000 (50.80)
R	2.266 (57.56)	4.000 (101.60)	2.000 (50.80)
S	2.532 (64.31)	4.266 (108.36)	2.000 (50.80)
T	2.813 (71.45)	4.281 (108.74)	2.000 (50.80)
U	3.125 (79.38)	4.322 (109.78)	2.000 (50.80)
V	3.500 (88.90)	4.375 (111.13)	2.000 (50.80)
W	4.000 (101.60)	4.500 (114.30)	2.000 (50.80)
X	4.750 (120.65)	4.750 (120.65)	2.000 (50.80)
Y	6.000 (152.40)	5.250 (133.35)	2.000 (50.80)

GENERAL NOTE: Drill all holes flat-bottomed and perpendicular to the scanning surface. Hole diameters shall be 0.250 ± 0.005 in. (6.35 ± 0.13 mm) in Faces #1 and #2, and 0.250 ± 0.002 in. (6.35 ± 0.05 mm) in Faces #3 and #4. Hole bottoms shall be parallel to the scanning surface to within 1 deg. Maximum radius of hole bottom corners shall be 0.010 in. (0.25 mm).

phenomena. As with other techniques, the phased array process assumes isotropic and homogeneous material whose acoustic velocity is constant and accurately known.

E-70 UT-AMPLITUDE TIME-OF-FLIGHT LOCUS-CURVE ANALYSIS TECHNIQUE

The UT-amplitude time-of-flight locus-curve analysis technique utilizes multiple probes in pulse-echo, transmitter-receiver, or tandem configuration. Individually selectable parameters control the compression of the A-scan information using a pattern-recognition algorithm, so that only the relevant A-scan amplitudes are stored and further processed.

The parameter values in the A-scan compression algorithm determine how many pre-cursing and how many post-cursing half-wave peaks must be smaller than a specific amplitude, so that this largest amplitude is identified as as relevant signal. These raw data can be displayed in B-, C-, and D-scan (side, top, and end view) presentations, with selectable color-code increments for amplitude and fast zoom capabilities. This operating mode is most suitable for detection purposes. For discrimination, a two-dimensional spatial-filtering algorithm is applied to search for correlation of the time-of-flight raw data with reflector-typical time-of-flight trajectories.

Tandem sizing and analysis uses techniques similar to pulse-echo but provides images that may be easier to interpret since the specular reflections from flaws oriented perpendicular to the surface are used. For cracks and planar flaws, the results should be verified with crack-tip-diffraction signals from the upper and lower end of the flaw since the acoustic parameters are very sensitive to flaw tip indications and a clear reconstruction image of these refraction phenomena is possible with this technique.

The location of indications within the image space is influenced by material thickness and actual sound velocity (i.e., isotropic and homogeneous material is assumed). However, deteriorating influences from anisotropic material (such as cladding) can be reduced by appropriate selection of the search unit parameters.

E-80 AUTOMATED DATA ACQUISITION AND IMAGING TECHNIQUE

Automated data acquisition and imaging is a multichannel technique that may be used for acquisition and analysis of UT data for both contact and immersion applications. This technique allows interfacing between the calibration, acquisition, and analysis modes; and for assignment of specific examination configurations. This technique utilizes a real-time display for monitoring the quality of data being collected, and provides for display of specific amplitude ranges and the capability to analyze peak data through target motion filtering. A cursor function allows scanning the RF data one waveform at a time to aid in crack sizing using tip-diffraction. For both peak and RF data, the technique

can collect, display, and analyze data for scanning in either the axial or circumferential directions.

This technique facilitates detection and sizing of both volumetric and planar flaws. For sizing volumetric flaws, amplitude-based methods may be used; and for sizing planar flaws, the crack-tip-diffraction method may be used. An overlay feature allows the analyst to generate a composite image using several sets of ultrasonic data. All data displayed in the analyze mode may be displayed with respect to the physical coordinates of the component.

APPENDIX F — NOZZLE EXAMINATION

F-10 GENERAL REQUIREMENTS

This Appendix provides rules for equipment and procedure qualification and/or requalification of manual or automated ultrasonic examinations of the nozzle inside radius. The Manufacturer, examination agency, or other user of this Appendix shall be responsible for qualifying the technique, equipment, and written procedure(s) in conformance with this Appendix, and/or as required by the referencing Code Section.

F-20 PERFORMANCE DEMONSTRATION FOR NOZZLE INSIDE RADIUS EXAMS

The equipment and procedure performance demonstration requirements specified in this Appendix may be satisfied simultaneously or in conjunction with other qualification(s)/verification and/or requalification demonstration in conformance with this Appendix.

(a) Ultrasonic instruments shall comply with the Instrument Requirements of F-30.

(b) Specimens to be employed during calibration and/or qualification test shall comply with the requirements of F-40.

(c) The equipment and procedure shall be considered qualified for detection of flaws upon successfully completing the performance demonstration specified in F-60, Procedure Qualification.

F-21 Personnel Requirements

Personnel shall be qualified and certified in accordance with the requirements of the referencing Code.

F-30 INSTRUMENT REQUIREMENTS

(a) A pulse-echo type of ultrasonic instrument and/or examination system shall be used. The instrument/system shall be equipped with a stepped gain control calibrated in units of 2.0 dB or less.

(b) The system shall exhibit the following:

(1) Center Frequency:

(a) For examination systems with bandwidths less than 30%, the center frequency shall not change more than ±5%.

(b) For examination systems with bandwidths 30% or greater, the system center frequency shall not vary more than ±10%.

(2) Bandwidth:

(a) The examination bandwidth shall not change more than ±10%.

NOTE: Bandwidth is measured at the −6 dB points.

F-31 Procedure Requirements

F-31.1 Written Procedure. Ultrasonic nozzle inside radius examination shall be performed in accordance with a written procedure. The procedure shall be qualified to the extent specified in this Subsection. The examination procedure shall contain a statement of scope that specifically defines the limits of procedure applicability. The examination procedure shall specify a single value or a range of values for the listed essential variables. The examination procedure shall specify, as a minimum, the following essential variables:

(a) instrument or system description including Manufacturer and model of pulser, receiver, and amplifier;

(b) ultrasonic technique;

(c) search units, including:

(1) number, size, shape, and configuration of active elements

(2) center frequency and either bandwidth or waveform for each active element

(3) mode of sound propagation; e.g., longitudinal, shear, etc.

(d) scanning equipment (when applicable);

(1) type; manipulator(s), bridges, semi-automatic devices

(2) indexing controls, scanners

(3) number of ultrasonic connectors; and length of cable

(e) scanning technique(s), including:

(1) scan pattern (modeling) and primary beam direction

(2) maximum scan speed

(3) minimum and maximum pulse repetition rate

(4) minimum sampling rate (automatic recording systems)

(5) extent of scanning and action to be taken for geometrical restrictions.

(f) methods of calibration for detection. Calibration methods include all those actions required to assure that the accuracy of the signal amplitude and sweep locations of the examination system (whether displayed, recorded, or automatically processed) are repeatable from examination to examination. Any method of achieving the system calibration shall be recorded. A description of the calibrated sensitivity shall be included in the procedure.

(g) minimum inspection/calibration data to be recorded, and medium, i.e., calibration sheet and/or magnetic disk;

(h) method of data recording, and recording equipment (strip chart, analog tape, digitizing);

(i) method and criteria for the discrimination of indications (e.g., geometric versus flaw), and for depth of flaws;

(j) surface condition requirements, scanner's mounting requirements;

(k) identification of qualification specimen, overall configuration; material, product form, shell thickness, bore barrel thickness and diameter(s);

(l) essential variable range(s).

F-31.2 Essential Variable Requalification. When the essential variables exceed the tolerances specified within the qualification procedure, the qualification test shall be repeated in conformance with F-60.

F-40 QUALIFICATION SPECIMEN

(a) The qualification process shall be conducted using a full-scale or partial section nozzle (mockup), which is dimensionally sufficient to contain the maximum beam path, examination volume, and the necessary reflectors that are to be detected.

(b) If the examining beams pass only through the nozzle forging, the mockup may be a nozzle forging, or segment of a forging, which may be fixed in a structure to simulate adjacent vessel surfaces as required for examination alignment. If the examining beams pass through the nozzle to shell weld, the mockup shall contain nozzle weld and shell components of sufficient size to permit qualification.

(c) The qualification specimen shall meet the requirements of the vessel specification(s) with respect to:

(1) the basic calibration block material requirements (J-10).

(2) Curvature. The examination and reflection surface curvatures on the nozzle mockup shall be similar to those curvatures on the nozzle in the vessel. The size ranges in F-40(c)(6) below shall be considered to be similar curvatures.

(3) welding process (when applicable).

(4) Cladding. If the inside surface of the nozzle in the vessel is clad, the inside surface of the nozzle mockup shall be clad using the same welding method (i.e., roll bonded, manual weld deposited, automatic wire deposited, or automatic strip deposited). In the event the cladding method is not known or is impractical to apply on the mockup, cladding may be applied using the manual weld deposit method. If the inside surface of the nozzle to be examined is not clad, the inside surface of the nozzle mockup may be cladded, as long as the reflectors are contained within the base metal interface to the required volume.

NOTE: Vessel cladding direction, where known, should be simulated.

(5) Thickness. Calibration specimen and/or mockup shall equal or exceed the maximum component thickness in the region to be qualified.

(6) Ratio limits for curved surfaces. Mockup diameter range in the area of qualification shall be determined by Fig. J-10. For diameters greater than 4 in. (102 mm), mockup curvature shall be in the range of 0.9 to 1.5 times the nozzle under examination.

F-50 QUALIFICATION SPECIMEN REFLECTORS

The qualification specimen shall contain a minimum of three reflectors within the examination volume for detection qualification. Optionally, induced or embedded cracks may be used in lieu of machined reflectors. Additionally these reflectors may be employed for demonstration of the procedure's sizing capabilities, when required by the referencing Code.

F-51 Reflectors

The qualification reflectors shall be distributed within the examination volume and shall meet the following requirements.

(a) Reflectors shall be distributed radially in two zones with at least one reflector in each zone. Zone 1 ranges between 0 deg. and 180 deg. (±45 deg.), Zone 2 is the remaining two quadrants, centered on the nozzle's horizontal axis.

(b) Machined reflectors shall be placed within the nozzle inner radii examination volume and specified to be oriented parallel to the axial radial plane of the nozzle within a manufacturing tolerance of ±2 deg.

(c) Machined reflectors shall be specified to be oriented perpendicular to the ID surface of the nozzle within a manufacturing tolerance of ±2 deg.

(d) Reflectors shall have a maximum length of 1.0 in. (25 mm), and a nominal width of 0.0625 in. (1.59 mm) (±10%).

(e) Machined reflectors shall have depth ranges, measured from the inside surface of the base material.

(1) Reflector No. 1 — 0.201–0.350

(2) Reflector No. 2 — 0.351–0.550

(3) Reflector No. 3 — 0.551–0.750

Induced crack reflectors are permitted, provided they are located in conformance with F-51(a) and (b) and their depths are within the range of reflectors in F-51(e).

F-60 PROCEDURE QUALIFICATION

The procedure shall be considered qualified for detection when all qualifying reflectors are located within 1.5 in. (38 mm) of their true position (x and y). Sizing qualification, when required, shall be in accordance with referencing Code requirements.

F-61 Requalification

The procedure shall require requalification when an essential variable of the qualified procedure has been changed and/or exceeded.

F-70 CALIBRATION

Calibration is defined as all of the processes necessary to configure the examination system prior to the examination that must be performed in order to satisfactorily qualify the equipment and procedure. Instrument calibration settings used during procedure qualification shall be repeated during subsequent field exams. Calibration simulators may be employed for field instrument calibration provided they can be correlated with the original calibration on the basic calibration block (if used) during the original calibration.

F-71 Calibration Checks

If used, subsequent calibration checks may be performed on either the qualification specimen, mockup, and/or simulator calibration block(s).

APPENDIX G

(In the Course of Preparation.)

APPENDIX H — RECORDING ANGLE BEAM EXAMINATION DATA FOR PLANAR REFLECTORS

H-10 RECORDING DATA

This Appendix describes a method for recording angle beam examination data for planar reflectors when amplitude based dimensioning is to be performed.

(a) Record all reflectors that produce a response equal to or greater than 20% of the distance-amplitude correction (DAC). However, the clad interface metallurgical reflectors and back wall reflections need not be recorded. Record surface reflectors that produce a response equal to or exceeding the calibration amplitude established per B-7(d). Record all search unit position and location dimensions to the nearest tenth of an inch.

(b) Obtain data from successive scans at increments no greater than nine-tenths of the transducer dimension measured parallel to the scan increment change (10% overlap). Record data for the end points as determined by 20% of DAC. Emphasis must be placed on measurement of the parameters determining the reflector length and height and the distances from the examination surface to the top and bottom of the reflector, since these dimensions are the factors most critical in determining ultimate evaluation and disposition of the flaw (see Appendix D for an illustrated example).

(c) The following reflector data shall be recorded when a reflector exceeds 20% DAC.

(1) Maximum percent of DAC, sweep reading of indication, search unit position, location along the length of the weld, and beam direction.

(2) Through-Wall Dimension

(a) For reflectors 20% to 100% DAC, the minimum sweep reading and its position and location along the length of the reflector for 20% DAC when approaching the reflector from the maximum signal direction.

(b) For reflectors 20% to 100% DAC, the maximum sweep reading and its position and location along the length of the reflector for 20% DAC when moving away from the reflector's maximum signal direction.

(c) For reflectors exceeding 100% DAC, minimum sweep reading and its position and location along the length of the reflector for 50% of the maximum amplitude when approaching the reflector from the maximum signal direction.

(d) For reflectors exceeding 100% DAC, maximum sweep reading and its position and location along the length of the reflector for 50% of the maximum amplitude when moving away from the reflector's maximum signal direction.

(3) *Length Dimension.* The length of the reflector shall be obtained by recording the position and location along the length of weld as determined by 20% of DAC for each end of the reflector.

APPENDIX I — EXAMINATION OF WELDS USING ANGLE BEAM SEARCH UNITS

I-10 EXAMINATION OF WELDS

This Appendix describes a method of examination of welds using angle beam search units.

I-20 GENERAL SCANNING REQUIREMENTS

Three angle beams, having nominal angles of 45 deg., 60 deg., and 70 deg. with respect to a perpendicular to the examination surface, shall generally be used. Beam angles other than 45 deg. and 60 deg. are permitted provided the measured difference between angles is at least 10 deg. Additional $\frac{1}{4}$ volume angle beam examination shall be conducted on the material volume within $\frac{1}{4}$ of the thickness adjacent to the examination surface. Single or dual element longitudinal or shear wave angle beams in the range of 60 deg. through 70 deg. with respect to perpendicular to the examination surface shall be used in this $\frac{1}{4}$ volume.

I-30 EXCEPTIONS TO GENERAL SCANNING REQUIREMENTS

Other angles may be used for examination of:

(a) flange welds, when the examination is conducted from the flange face;

(b) nozzles and nozzle welds, when the examination is conducted from the nozzle bore;

(c) attachment and support welds;

(d) examination of double taper junctures.

APPENDIX J — BASIC CALIBRATION BLOCK

This Appendix contains the description for a basic calibration block used for distance-amplitude correction (DAC) calibration techniques.

The basic calibration block(s) containing basic calibration reflectors to establish a primary reference response of the equipment and to construct a distance-amplitude correction curve shall be as shown in Fig. J-10. The basic calibration reflectors shall be located either in the component material or in a basic calibration block.

J-10 BASIC CALIBRATION BLOCK MATERIAL

(a) *Block Selection.* The material from which the block is fabricated shall be from one of the following:

(1) nozzle dropout from the component;

(2) a component prolongation;

(3) material of the same material specification, product form, and heat treatment condition as the material to which the search unit is applied during the examination.

(b) *Clad.* Where the component material is clad and the cladding is a factor during examination, the block shall be clad to the component clad nominal thickness $\pm\frac{1}{8}$ in. (3.2 mm). Deposition of clad shall be by the same method (i.e., rollbonded, manual weld deposited, automatic wire deposited, or automatic strip deposited) as used to clad the component to be examined. In the event the cladding method is not known or the method of cladding used on the component is impractical for block cladding, deposition of clad shall be by the manual method. It is desirable to have component materials which have been clad before the drop outs or prolongations are removed. When the parent material on opposite sides of a weld are clad by different methods, the cladding on the calibration block shall be applied by the method used on the side of the weld from which the examination will be conducted. When the examination is conducted from both sides, the calibration block shall provide for calibration for both methods of cladding.

(c) *Heat Treatment.* The calibration block shall receive at least the minimum tempering treatment required by the material specification for the type and grade and a postweld heat treatment of at least 2 hr.

(d) *Surface Finish.* The finish on the surfaces of the block shall be representative of the surface finishes of the component.

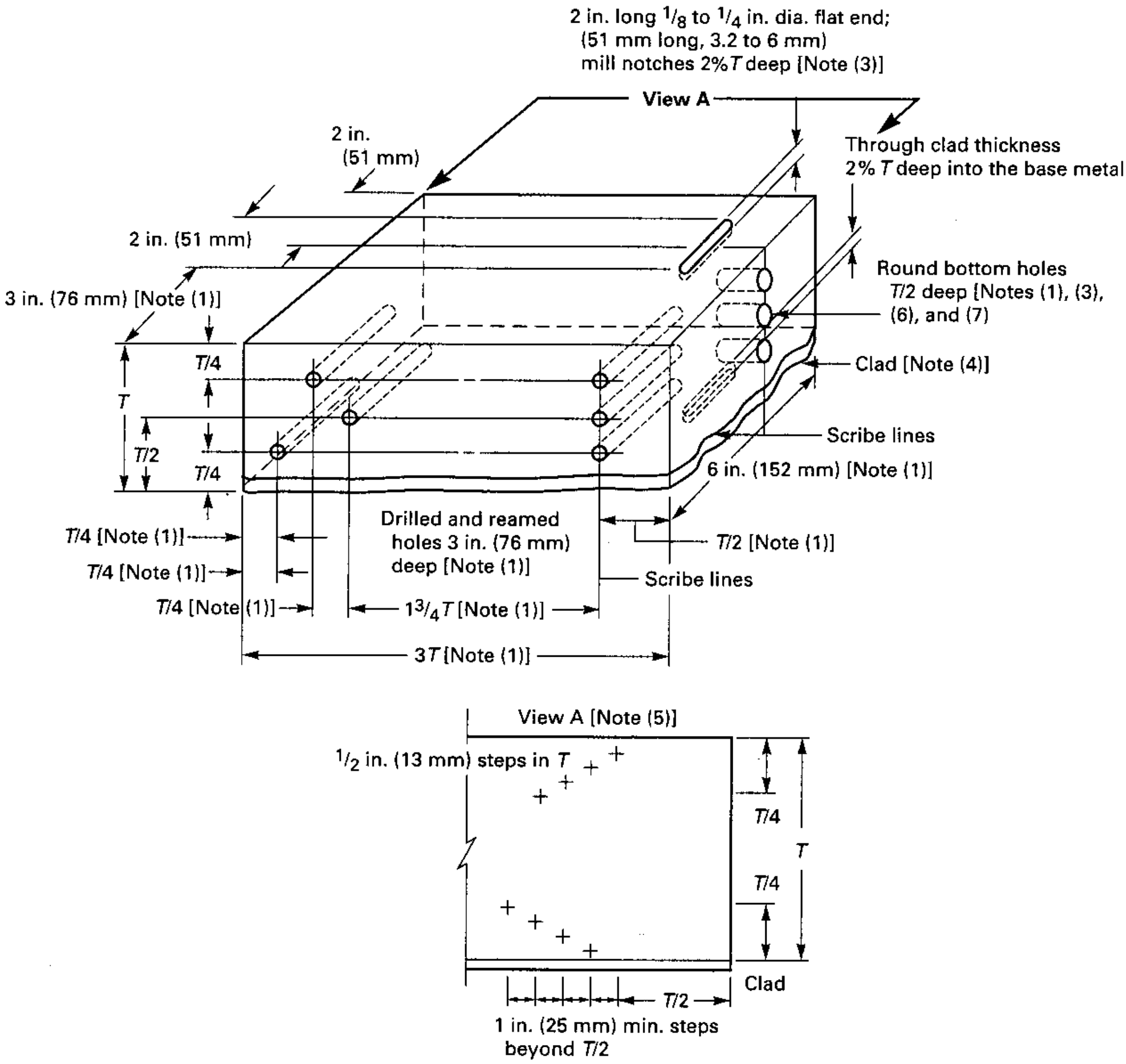


FIG. J-10 BASIC CALIBRATION BLOCK

Weld Thickness t, in. (mm)	Basic Calibration Block Thickness T, in. (mm)	Side Drilled Hole Diameter, in. (mm) [Note (3)]	Round Bottom Hole Diameter, in. (mm) [Notes (3) and (6)]
Over 2 through 4 (51 through 102)	3 or t (76 or t)	$^3/_{16}$ (4.8)	$^3/_8$ (9.5)
Over 4 through 6 (102 through 152)	5 or t (127 or t)	$^1/_4$ (6.4)	$^7/_{16}$ (11.1)
Over 6 through 8 (152 through 203)	7 or t (178 or t)	$^5/_{16}$ (7.9)	$^1/_2$ (12.7)
Over 8 through 10 (203 through 254)	9 or t (230 or t)	$^3/_8$ (9.5)	$^9/_{16}$ (14.3)
Over 10 through 12 (254 through 305)	11 or t (280 or t)	$^7/_{16}$ (11.1)	$^5/_8$ (15.9)
Over 12 through 14 (305 through 356)	13 or t (330 or t)	$^1/_2$ (12.7)	$^{11}/_{16}$ (17.5)
Over 14 (356)	$t \pm 1$ ($t \pm 25$)	[Note (2)]	[Note (2)]

NOTES:
(1) Minimum dimensions.
(2) For each increase in weld thickness of 2 in. (50.8 mm) or fraction thereof over 14 in. (356 mm), the hole diameter shall increase $^1/_{16}$ in. (1.6 mm).
(3) The tolerances for the hole diameters shall be $\pm {}^1/_{32}$ in. (0.8 mm); tolerances on notch depth shall be +10 and −20% (need only be held at the thinnest clad thickness along the reflecting surface of the notch); tolerance on hole location through the thickness shall be $\pm {}^1/_8$ in. (3.2 mm); perpendicular tolerances on notch reflecting surface shall be ± 2 deg; tolerance on notch length shall be $\pm {}^1/_4$ in. (± 6.4 mm).
(4) Clad shall not be included in T.
(5) Subsurface calibration holes $^1/_8$ in. (3.2 mm) (maximum) diameter by $1^1/_2$ in. (38.1 mm) deep (minimum) shall be drilled at the clad-to-base metal interface and at $^1/_2$ in. (12.7 mm) increments through $T/4$ from the clad surface, also at $^1/_2$ in. (12.7 mm) from the unclad surface and at $^1/_2$ in. (12.7 mm) increments through $T/4$ from the unclad surface. In each case, the hole nearest the surface shall be drilled at $T/2$ from the edge of the block. Holes at $^1/_2$ in. (12.7 mm) thickness increments from the near surface hole shall be drilled at 1 in. (25.4 mm) minimum intervals from $T/2$.
(6) Round (hemispherical) bottom holes shall be drilled only when required by a Referencing Code Section for beam spread measurements (see T-434.1) and the technique of B-60 is used. The round bottom holes may be located in the largest block in a set of basic calibration blocks, or in a separate block representing the maximum thickness to be examined.
(7) $T/2$ hole may be located in the opposite end of the block.

FIG. J-10 BASIC CALIBRATION BLOCK (CONT'D)

(e) Block Quality. The calibration block material shall be completely examined with a straight beam search unit. Areas that contain indications exceeding the remaining back reflection shall be excluded from the beam paths required to reach the various calibration reflectors.

J-20 CALIBRATION REFLECTORS

(a) Basic Calibration Reflectors. The side of a hole drilled with its axis parallel to the examination surface is the basic calibration reflector. A square notch shall also be used. The reflecting surface of the notches shall be perpendicular to the block surface. See Fig. J-10.

(b) Scribe Line. A scribe line as shown in Fig. J-10 shall be made in the thickness direction through the in-line hole center lines and continued across the two examination surfaces of the block.

(c) Additional Reflectors. Additional reflectors may be installed; these reflectors shall not interfere with establishing the primary reference.

(d) Basic Calibration Block Configuration. Figure J-10 shows block configuration with hole size and location. Each weld thickness on the component must be represented by a block having a thickness relative to the component weld as shown in Fig. J-10. Where the block thickness ±1 in. (25 mm) spans two of the weld thickness ranges shown in Fig. J-10, the block's use shall be acceptable in those portions of each thickness range covered by 1 in. (25 mm). The holes shall be in accordance with the thickness of the block. Where two or more base material thicknesses are involved, the calibration block thickness shall be sufficient to contain the entire examination beam path.

(e) Welds in Materials With Diameters Greater Than 20 in. (508 mm). For examination of welds in materials where the examination surface diameter is greater than 20 in. (508 mm), a single curved basic calibration block may be used to calibrate the straight and angle beam examinations on surfaces in the range of curvature from 0.9 to 1.5 times the basic calibration block diameter. Alternatively, a flat basic calibration block may be used provided the minimum convex, concave, or

compound curvature radius to be examined is greater than the critical radius determined by Article 5 of Appendix A. For the purpose of this determination, the dimension of the straight or angle beam search units flat contact surface tangent to the minimum radius shall be used instead of the transducer diameter in Table A-10.

(f) Welds in Materials With Diameters 20 in. (508 mm) and Less. The basic calibration block shall be curved for welds in materials with diameters 20 in. (508 mm) and less. A single curved basic calibration block may be used to calibrate the examination on surfaces in the range of curvature from 0.9 to 1.5 times the basic calibration block diameter. For example, an 8 in. (203 mm) diameter curved block may be used to calibrate the examination on surfaces in the range of curvature from 7.2 in. (183 mm) to 12 in. (305 mm) diameter. The curvature range from 0.94 in. (24 mm) to 20 in. (508 mm) diameter requires six block curvatures as indicated in Fig. J-20 for any thickness range as indicated in Fig. J-10.

(g) Retention and Control. All basic calibration blocks for the examination shall meet the retention and control requirements of the referencing Code Section.

APPENDIX K — RECORDING STRAIGHT BEAM EXAMINATION DATA FOR PLANAR REFLECTORS

This Appendix describes a method for recording straight beam examination data for planar reflectors when amplitude based dimensioning is to be performed.

(a) Record all reflectors that produce a response equal to or greater than 50% of the distance-amplitude correction (DAC). However, clad interface and back wall reflections need not be recorded. Record all search unit position and location dimensions to the nearest tenth of an inch.

(b) Obtain data from successive scans at increments no greater than nine-tenths of the transducer dimension measured parallel to the scan increment change (10% overlap). Record data for the end points as determined by 50% of DAC.

APPENDIX L — EXAMINATION OF BOLTS AND STUDS

L-10 GENERAL REQUIREMENTS

This Appendix provides guidance for examining bolts and studs from the end face after threading by the axial-straight beam technique to locate and evaluate service-induced discontinuities. When the referencing Code Section requires examination per this Appendix, the axial straight beam examinations shall be performed over an entire end surface and the following paragraphs shall apply.

L-11 Written Procedure Requirements

Ultrasonic examination shall be performed in accordance with a written procedure that shall include the following information:

(a) bolt or stud configurations to be examined, including length, diameter, thread size, plating, materials, and product form (e.g., bolt or stud, rolled or cut thread);

(b) scanning surfaces, surface condition requirements, and surface preparation methods;

(c) equipment used, including the following information;

(1) make and model of instrument;

(2) search units type, angle, frequency, and transducer (crystal size);

(3) sizes and configurations of wedges and shoes;

(4) automatic alarm recording equipment;

(5) rotating, revolving, or scanning equipment;

(6) couplant, and

(7) search unit cable type, length, and number of connectors.

(d) examination technique including angles, modes of wave propagation in the material, directions, maximum speed, and extent of scanning;

(e) techniques of calibration and of establishing scanning sensitivity levels, including instrument controls to be used and acceptance standards for the calibrated condition;

(f) identification of calibration blocks;

(g) data to be recorded and method of recording;

(h) detectability limitation and location accuracy;

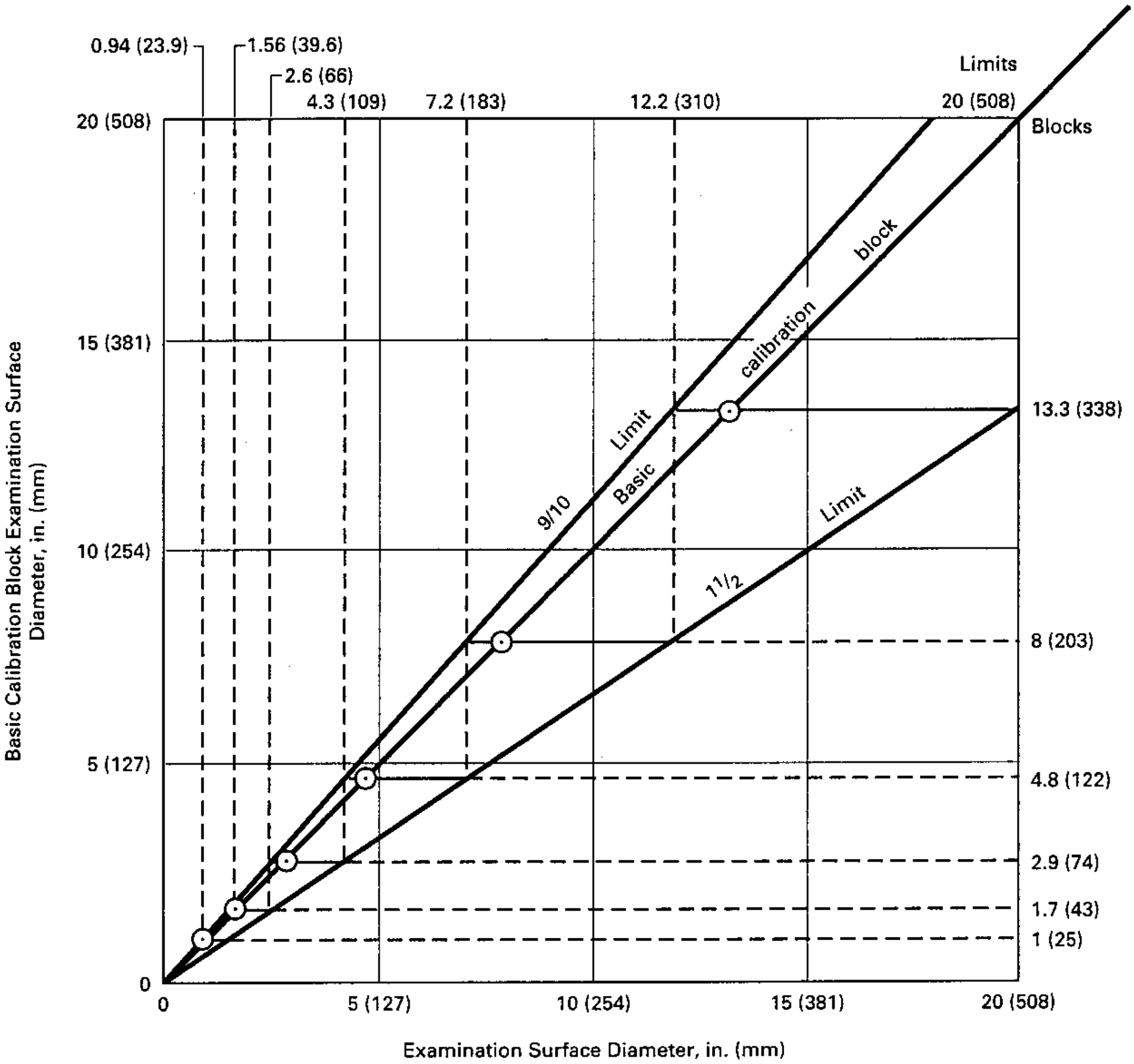
(i) examination volume covered considering loss in coverage from near and far surface resolution limitations;

(j) methods of data interpretation and plotting; and

(k) personnel qualification requirements.

L-12 Search Units

Search units may contain either single or dual elements. Search units with angled contact wedges may be used to aid in ultrasonic coupling. Calibration shall be performed with the contact wedges used during the examination.



GENERAL NOTES:

(a) Plot examination surface of basic calibration block on diagonal (45 deg) line.

(b) Draw horizontal line through that point from the 9/10 to the $1^1/_2$ limit line.

(c) The ends of this line read on the horizontal scale give the range of examination surface diameters which may be examined with a system calibrated on this block.

(d) Thickness range requirements shall also be satisfied.

FIG. J-20 RATIO LIMITS FOR CURVED SURFACES

TABLE L-13.1
NOTCH DIMENSIONS

Bolt or Stud Size	Maximum Notch Dimensions: Depth[1], in.	(mm)	Reflective Area[2], sq. in.	(mm^2)
Greater than 4 in. (102 mm) diameter	0.157	(3.99)	0.059	(38.06)
2 in. (51 mm) diameter and greater, but not over 4 in. (102 mm) diameter	0.107	(2.72)	0.027	(17.42)

NOTES:
(1) For threaded surfaces, depth is measured from bottom of thread root to bottom of notch.
(2) Reflective area shall be no larger than the required area.

L-13 Basic Calibration Block

A system calibration shall be performed using a full-scale or partial section bolt or stud which is sufficient to contain the sound beam path and the area of interest, and to demonstrate the scanning technique.

(a) The basic calibration block shall be of the same material specification, product form, and surface finish as the bolt or stud to be examined.

(b) Reflectors shall be notches with a depth and area as specified in Table L-13.1 at the minimum end and maximum metal paths except that notches need not be located closer than one diameter from either end.

If these notches are in the threaded section, they shall be machined from the base of the thread root and shall follow the beam angle of the thread. If the notches are located in the cylindrical outer surface and the inner bore surface, they shall be machined on the circumferential axis of the bolt or stud.

(c) Additional reflectors may be used provided they do not interfere with detection of the required notches.

(d) The finish on the surface of the basic calibration block shall be maintained similar to the finish existing during qualification.

(e) The size and shape of the notches may vary depending upon the type of notch. Several configurations of notches are shown in Fig. L-13-1 representing straight, circular, and rectangular/square notches on the outside surface. Rectangular and circular notches are also possible for the inside surface of bore holes. Other shapes of notches on both the external and internal surfaces may be made.

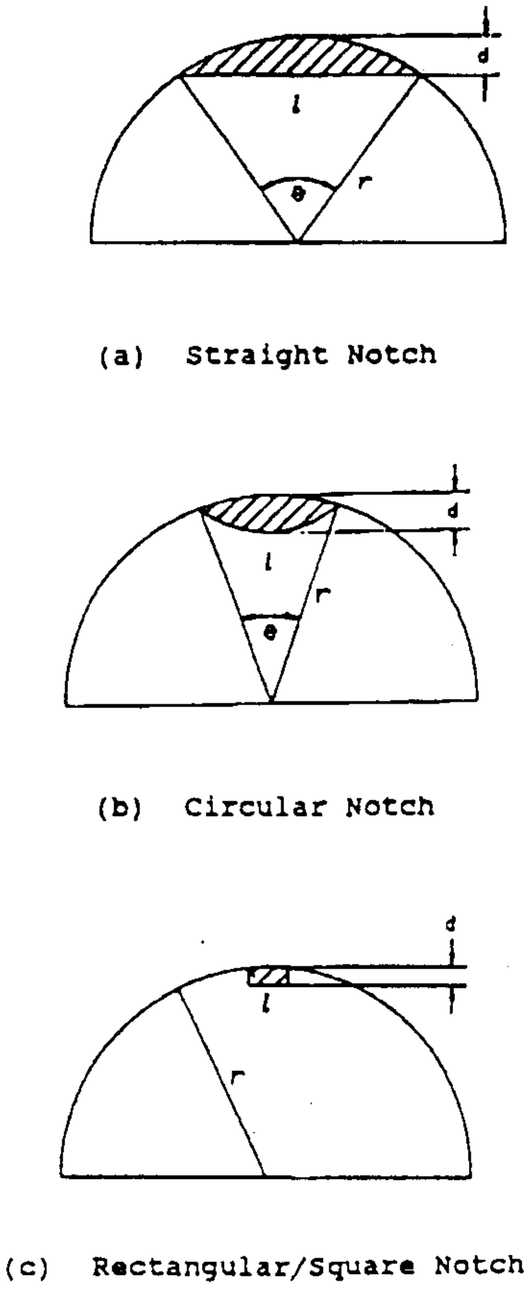


FIG. L-13-1 VARIOUS CALIBRATION NOTCH CONFIGURATIONS FOR OUTSIDE SURFACE REFLECTORS

The area of a straight cutter notch (see Fig. L-13-1a) is given by the following formula:

$$A = \left[\sin^{-1}\left(\frac{L}{2R}\right)\right] R^2 - 0.5\,(L)\,(R - d)$$

where
A = area of notch
L = length of notch (cord)
R = minimum thread radius
d = depth of notch
$L/2R$ is in rads

The length L can be given as a function of d and R as follows:

$$L = \sqrt{8\,dR - 4\,d^2}$$

Several straight notch depths and lengths have been calculated for various sizes of 8-Thread Series (8-UN/8-UNR) studs and bolts and are presented in Table L-13.2.

L-20 CALIBRATION

L-21 General Requirements

Calibration shall be performed in accordance with T-460 and shall be performed using the complete ultrasonic examination system.

(a) Complete ultrasonic examination system calibration shall be performed each day prior to use of the system and for each bolt or stud configuration.

(b) For contact examination, the temperature differential between the examination and basic calibration block surfaces shall be within 25°F (14°C). For immersion examination, the couplant temperature for calibration shall be within 25°F (14°C) of the couplant temperature used during actual scanning. When either of these conditions is not achievable, appropriate compensations for velocity related variables (e.g., angle and sensitivity changes) shall be made.

(c) Any control which affects the instrument linearity (e.g., filters, reject, etc.) shall be in the off or minimum position for linearity check, calibration, and examination.

L-22 Calibration Confirmation

(a) Instrument Linearity. Instrument qualifications for screen height and amplitude control linearity shall be performed in accordance with Article 4, T-431.2.

(b) System Calibration Check

(1) A system calibration check shall verify the instrument sensitivity and sweep range calibration at the start and finish of the examinations, with any change in examination personnel, and at least every 12 hours during an examination.

(2) A system calibration check shall be performed when search units, shoes, couplants, cables, ultrasonic instruments, recording devices, or any other parts of the examination system are changed.

(c) Sensitivity. If the response from a calibration reflector notch has decreased more than 20% or 2 dB from its initial amplitude, all data records since the last calibration check shall be marked void or deleted. A new calibration shall be recorded and examinations performed since the last acceptable calibration check shall be repeated. If the response from a calibration reflector notch has increased more than 20% or 2 dB from its initial amplitude, recorded indications taken since the last valid calibration check may be reexamined with the correct calibration and their values changed on the data sheets.

L-23 Calibration Record

The following calibration data shall be recorded on a calibration sheet:

(a) calibration sheet identification and date, examination personnel;

(b) examination procedure number and revision;

(c) basic calibration block identification;

(d) ultrasonic instrument identification, serial number, and control settings;

(e) beam angle, couplant, and mode of wave propagation in the material;

(f) orientation of search unit with respect to the bolt or stud;

(g) search unit manufacturer, identification number, serial number, nominal frequency, and size;

(h) identification of fixtures and types or serial numbers of wedges and shoes (if used);

(i) search unit cable type, length, and number of connectors;

(j) times of initial calibration and subsequent calibration checks;

(k) amplitudes and sweep readings obtained from the calibration reflectors;

(l) if an electronic DAC is being used, a record shall be made of the resultant amplitudes and sweep readings obtained from the calibration reflectors after DAC correction; and

(m) calibration gain settings.

TABLE L-13.2
TYPICAL STRAIGHT NOTCH DIMENSIONS AS A FUNCTION OF NOTCH AREA AND STUD OR BOLT SIZE DIMENSIONS FOR 8-THREAD SERIES (8-UN/8-UNR)

Bolt Nominal Size	Bolt Minor Dia.		Bolt [Note (1)] Area		Notch Area		Notch Depth		Notch Length		Notch Area as % of Bolt Area
	in.	mm	in.^{2}	mm^2	in.^{2}	mm^2	in.	mm	in.	mm	
2	1.8647	47.363	2.731	1 761.93	0.027	17.42	0.061	1.55	0.863	21.92	0.989
	1.9897	50.538	3.109	2 005.80	0.027	17.42	0.060	1.52	0.681	17.30	0.868
2.25	2.1147	53.713	3.512	2 265.80	0.027	17.42	0.058	1.47	0.691	17.55	0.769
	2.2397	56.888	3.940	2 541.93	0.027	17.42	0.057	1.45	0.705	17.91	0.685
2.5	2.3647	60.063	4.392	2 833.54	0.027	17.42	0.056	1.42	0.719	18.26	0.615
	2.4897	63.238	4.868	3 140.64	0.027	17.42	0.055	1.40	0.732	18.59	0.555
2.75	2.6147	66.413	5.369	3 463.86	0.027	17.42	0.054	1.37	0.744	18.90	0.503
	2.7397	69.588	5.895	3 803.22	0.027	17.42	0.053	1.35	0.755	19.18	0.458
3	2.8647	72.763	6.445	4 158.06	0.027	17.42	0.053	1.35	0.772	19.61	0.419
	2.9897	75.938	7.020	4 529.02	0.027	17.42	0.052	1.32	0.782	19.86	0.385
3.25	3.1147	79.113	7.619	4 915.47	0.027	17.42	0.051	1.30	0.791	20.09	0.354
	3.2397	82.288	8.243	5 318.05	0.027	17.42	0.050	1.27	0.799	20.29	0.328
3.5	3.3647	85.463	8.892	5 736.76	0.027	17.42	0.050	1.27	0.814	20.68	0.304
	3.4897	88.638	9.565	6 170.96	0.027	17.42	0.049	1.24	0.821	20.85	0.282
3.75	3.6147	91.813	10.262	6 620.63	0.027	17.42	0.049	1.24	0.836	21.23	0.263
	3.7397	94.988	10.984	7 086.44	0.027	17.42	0.048	1.22	0.842	21.39	0.246
4	3.8647	98.163	11.731	7 568.37	0.027	17.42	0.048	1.22	0.856	21.74	0.230
	3.9897	101.338	12.502	8 065.79	0.027	17.42	0.047	1.19	0.861	21.87	0.216
4.25	4.1147	104.513	13.297	8 578.69	0.059	38.06	0.078	1.98	1.122	28.50	0.444
	4.2397	107.688	14.118	9 108.37	0.059	38.06	0.078	1.98	1.139	28.93	0.418
4.5	4.3647	110.863	14.962	9 652.88	0.059	38.06	0.077	1.96	1.149	29.18	0.394
	4.4897	114.038	15.832	10 214.17	0.059	38.06	0.076	1.93	1.158	29.41	0.373
4.75	4.6147	117.213	16.725	10 790.30	0.059	38.06	0.075	1.91	1.167	29.64	0.353
	4.7397	120.388	17.644	11 383.20	0.059	38.06	0.075	1.91	1.183	30.05	0.334
5	4.8647	123.563	18.587	11 991.59	0.059	38.06	0.074	1.88	1.191	30.25	0.317
	4.9897	126.738	19.554	12 615.46	0.059	38.06	0.074	1.88	1.202	30.53	0.302
5.25	5.1147	129.913	20.546	13 255.46	0.059	38.06	0.073	1.85	1.213	30.81	0.287
	5.2397	133.088	21.563	13 911.59	0.059	38.06	0.072	1.83	1.220	30.99	0.274
5.5	5.3647	136.263	22.604	14 583.20	0.059	38.06	0.072	1.83	1.235	31.37	0.261
	5.4897	139.438	23.669	15 270.29	0.059	38.06	0.071	1.80	1.241	31.52	0.249
5.75	5.6147	142.613	24.760	15 974.16	0.059	38.06	0.071	1.80	1.250	31.75	0.238
	5.7397	145.788	25.874	16 692.87	0.059	38.06	0.070	1.78	1.260	32.00	0.228
6	5.8647	148.963	27.014	17 428.35	0.059	38.06	0.070	1.78	1.269	32.23	0.218

NOTE:
(1) Bolt area is calculated using bolt minor diameter.

L-30 EXAMINATION

L-31 General Examination Requirements

Examination shall be performed by moving the search unit over the examination surface so as to scan the entire examination volume. As a minimum, each pass of the search unit shall overlap a minimum of 50% of the transducer (piezoelectric element) dimension perpendicular to the direction of the scan.

L-32 Rate of Search Unit Movement

The rate of search unit movement shall not exceed the maximum rate demonstrated to detect the calibration reflectors.

L-33 Scanning Sensitivity

If the noise level permits, the scanning sensitivity shall be a minimum of 6 dB above the reference level. However, evaluations shall be performed at the reference level.

L-34 Surface Preparation

The examination surfaces shall be free of irregularities (e.g., raised markings, scale, or loose foreign matter) or coatings which interfere with ultrasonic wave transmission into the material.

L-35 Record

The following data shall be recorded:

(a) record identification, date, and time period of examination;

(b) identification and qualification levels of examination personnel;

(c) examination procedure and revision;

(d) applicable calibration sheet information;

(e) bolt or stud identification; and

(f) surfaces from which the examination is conducted (when the examination technique requires subdivisions of the examination surface or more than one examination surface, they shall be identified in the data record).

(g) Indications. For each indication required to be recorded by L-11 written procedure, the following information shall be recorded:

(1) search unit position;

(2) scan direction;

(3) metal path (sweep reading);

(4) signal amplitude at maximum response; and

(5) signal-to-noise ratio.

ARTICLE 5

Figures

Tables

Mandatory Appendices

Figure

Nonmandatory Appendix

Figures

Table

ARTICLE 5
ULTRASONIC EXAMINATION METHODS FOR MATERIALS AND FABRICATION

T-510 SCOPE

This Article describes or references requirements which are to be used in selecting and developing [see T-110(c)] ultrasonic examination procedures for welds, parts, components, materials, and thickness determinations. This Article contains all of the basic technical and methodological requirements for ultrasonic examination. When examination to any part of this Article is a requirement of a referencing Code Section, the referencing Code Section shall be consulted for specific requirements for the following:

Personnel Qualification/Certification Requirements
Procedure Requirements and/or Techniques
Examination System Characteristics
Retention and Control of Calibration Blocks
Acceptance Standards to Be Used for Evaluation
Extent and Retention of Records
Report Requirements
Extent of Examination and/or Volume to be Scanned

T-520 GENERAL REQUIREMENTS

T-521 Basic Requirements and Terms Used

When this Article is specified by a referencing Code Section, the ultrasonic method described in this Article shall be used together with Article 1, General Requirements. Definitions of terms used in this Article are in Mandatory Appendix III of this Article. When SA, SB, and SE documents are referenced, they are located in Article 23.

01 T-522 Procedure Requirements

Ultrasonic examination shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable:

(a) weld and/or material types and configurations to be examined, including thickness dimensions, and product form (casting, forging, plate, etc.);

(b) the surface or surfaces from which the examination shall be performed;

(c) surface condition;

(d) couplant, brand name, or types;

(e) technique (straight beam, angled beam, contact, and/or immersion);

(f) angles and mode(s) of wave propagation in the material;

(g) search unit type, frequency(ies), and transducer size(s);

(h) special search units, wedges, shoes, or saddles;

(i) ultrasonic instrument type(s);

(j) description of calibration: blocks and techniques;

(k) directions and extent of scanning;

(l) data to be recorded and method of recording (manual or mechanized);

(m) automatic alarm and recording equipment, or both;

(n) rotating, revolving, or scanning mechanisms; and

(o) post-examination cleaning.

T-523 General Examination Requirements for Other Than Thickness Measurements

T-523.1 Examination Coverage. The volume shall be examined by moving the search unit over the examination surface so as to scan the entire examination volume. Each pass of the search unit shall overlap a minimum of 10% of the transducer (piezoelectric element) dimension perpendicular to the direction of the scan.

T-523.2 Rate of Search Unit Movements. The rate of search unit movement for examination shall not exceed 6 in./sec (152 mm/s) unless calibration is verified at scanning speed.

T-523.3 Recording Sensitivity Level. For both manual and mechanized examinations recording of indications shall be made with respect to the reference level.

T-530 EQUIPMENT AND SUPPLIES

T-531 Frequency

This examination shall be conducted with a pulse-echo ultrasonic instrument capable of generating frequencies over the range of at least 1 MHz to 5 MHz. Instruments operating at other frequencies may be used if equal or better sensitivity can be demonstrated and documented.

T-532 Screen Height Linearity

The ultrasonic instrument shall provide linear vertical presentation within ±5% of the full screen height for 20% to 80% of the calibrated screen height [base line to maximum calibrated screen point(s)]. The procedure for evaluating screen height linearity is provided in Appendix I and shall be performed at the beginning of each period of extended use (or every 3 months, whichever is less).

T-533 Amplitude Control Linearity

The ultrasonic instrument shall utilize an amplitude control accurate over its useful range to ±20% of the nominal amplitude ratio, to allow measurement of indications beyond the linear range of the vertical display on the screen. The procedure for evaluating amplitude control linearity is given in Appendix II and shall be performed at the beginning of each period of extended use (or every 3 months, whichever is less).

T-534 Checking and Calibration of Equipment

The proper functioning of the examination equipment shall be checked and the equipment shall be calibrated by the use of the calibration standard at the beginning and end of each examination, when examination personnel are changed, and at any time that malfunctioning is suspected, as a minimum.

If during any check it is determined that the testing equipment is not functioning properly, all of the product that has been tested since the last valid equipment calibration shall be reexamined.

T-536 Search Units

(a) Search units may contain either single or dual transducer elements.

(b) Search units with contoured contact wedges may be used to aid ultrasonic coupling. Calibration shall be done with the contact wedges used during the examination.

T-540 APPLICATIONS

T-541 Material Product Forms

T-541.1 Plate. Procedures used for ultrasonic examination of plate shall conform to the following applicable standards in Article 23, supplemented by T-510 and T-520, as well as T-541.1.1, T-541.1.2, and T-541.1.3: 01

(a) SA-435/SA-435M Standard Specification for Straight-Beam Ultrasonic Examination of Steel Plates

(b) SA-577/SA-577M Standard Specification for Ultrasonic Angle-Beam Examination of Steel Plates

(c) SA-578/SA-578M Standard Specification for Straight-Beam Ultrasonic Examination of Plain and Clad Steel Plates for Special Applications

(d) SB-548 Standard Method for Ultrasonic Inspection of Aluminum-Alloy Plate for Pressure Vessels

T-541.1.1 Equipment. The requirements for equipment shall be in accordance with T-530.

T-541.1.2 Calibration. The calibration requirements shall be in accordance with the applicable standard listed in T-541.1, or as supplemented by the referencing Code Section.

T-541.1.3 Examination. The requirements for examination shall be in accordance with the applicable standard listed in T-541.1. Examinations for final acceptance shall be performed after the plate rolling to size and after heat treatment.

T-541.2 Forgings and Bars. Procedures used for ultrasonic examination of forgings and bars shall conform to the following applicable standards in Article 23, supplemented by T-510 and T-520, as well as T-541.2.1, T-541.2.2, and T-541.2.3: 01

(a) SA-388 Standard Practice for Ultrasonic Examination of Heavy Steel Forgings

(b) SA-745 Standard Practice for Ultrasonic Examination of Austenitic Steel Forgings

T-541.2.1 Equipment. The requirements for equipment shall be in accordance with T-530.

T-541.2.2 Calibration. The calibration requirements shall be in accordance with the applicable standard listed in T-541.2.

T-541.2.3 Examination. The requirements for examination shall be selected in accordance with the applicable standard listed in T-541.2, except as listed in (a) through (d) below.

(a) All forgings and bars shall be examined by the ultrasonic method, using the straight beam technique.

(b) Ring forgings and other hollow forgings shall, in addition, be examined using the angle beam technique in two circumferential directions, unless wall thickness or geometric configuration makes angle beam examinations impractical.

(c) In addition to (a) and (b) above, ring forgings made to fine grain melting practices and used for vessel shell sections shall also be examined by angle beam technique in two axial directions.

(d) Immersion techniques may be used.

01 **T-541.3 Tubular Products.** Procedures used for ultrasonic examination of pipe, tubing, and fittings shall conform to the following applicable standards in Article 23, supplemented by T-510 and T-520, as well as T-541.3.1, T-541.3.2, and T-541.3.3.

(a) SE-213 Standard Practice for Ultrasonic Examination of Metal Pipe and Tubing

(b) SE-273 Standard Practice for Ultrasonic Examination of Longitudinal and Welded Pipe and Tubing

T-541.3.1 Equipment. The requirements shall be in accordance with T-530.

T-541.3.2 Calibration. The calibration requirements shall be selected in accordance with the applicable standard listed in T-541.3, as well as (a) and (b) below.

(a) The calibration block shall be of the same nominal diameter and thickness and of the same nominal composition and heat treatment condition as the product that is being examined. The calibration reflectors shall be axial notches or grooves on the outside and the inside surfaces of the calibration block, and shall have a length of approximately 1 in. (25 mm) or less, a width not to exceed $\frac{1}{16}$ in. (1.6 mm), and a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the nominal wall thickness. The calibration block may be the product being examined.

(b) The calibration block shall be long enough to simulate the handling of the product being examined through the examination equipment. When more than one calibration reflector is placed in a calibration block, the reflector shall be located so that indications from each reflector are separate and distinct, without mutual interference or amplification.

T-541.3.3 Examination. The requirements for examination shall be selected in accordance with the applicable standard listed in T-541.3.

T-541.4 Castings. When ultrasonic examination of ferritic castings is required by the referencing Code Section, all sections, regardless of thickness, shall be examined in accordance with SA-609, supplemented by T-510 and T-520, as well as T-541.4.1, T-541.4.2, and T-541.4.3.

T-541.4.1 Equipment. The requirements for equipment shall be in accordance with T-530, supplemented by (a) and (b) below.

(a) The transducer shall be 1 or $1\frac{1}{8}$ in. (25 or 29 mm) in diameter, or 1 sq in. (645 mm^2), maximum.

(b) 1 MHz search units shall be used for examination, although other frequencies may be used for evaluation if equal or better sensitivity can be demonstrated and documented.

T-541.4.2 Calibration

T-541.4.2.1 Calibration Blocks. The block or blocks required to establish the examination sensitivity across the full thickness of the castings to be examined shall be made of material of the same specification, grade, product form, heat treatment, and thickness ±25% as the castings to be examined. The surface finish of the calibration block shall be representative of the examination surface of the casting to be examined.

(a) Straight Beam. Calibration blocks meeting the requirements described in T-541.4.2.1 and in SA-609 shall be used.

(b) Angle Beam. The basic calibration block shall be as shown in Fig. T-541.4.1.2(b). Holes of larger or smaller diameters, V- or square notches may also be placed in the calibration block to provide reference reflectors for evaluation purposes. These additional holes and notches shall be located so as not to interfere with the responses from the basic calibration reflectors.

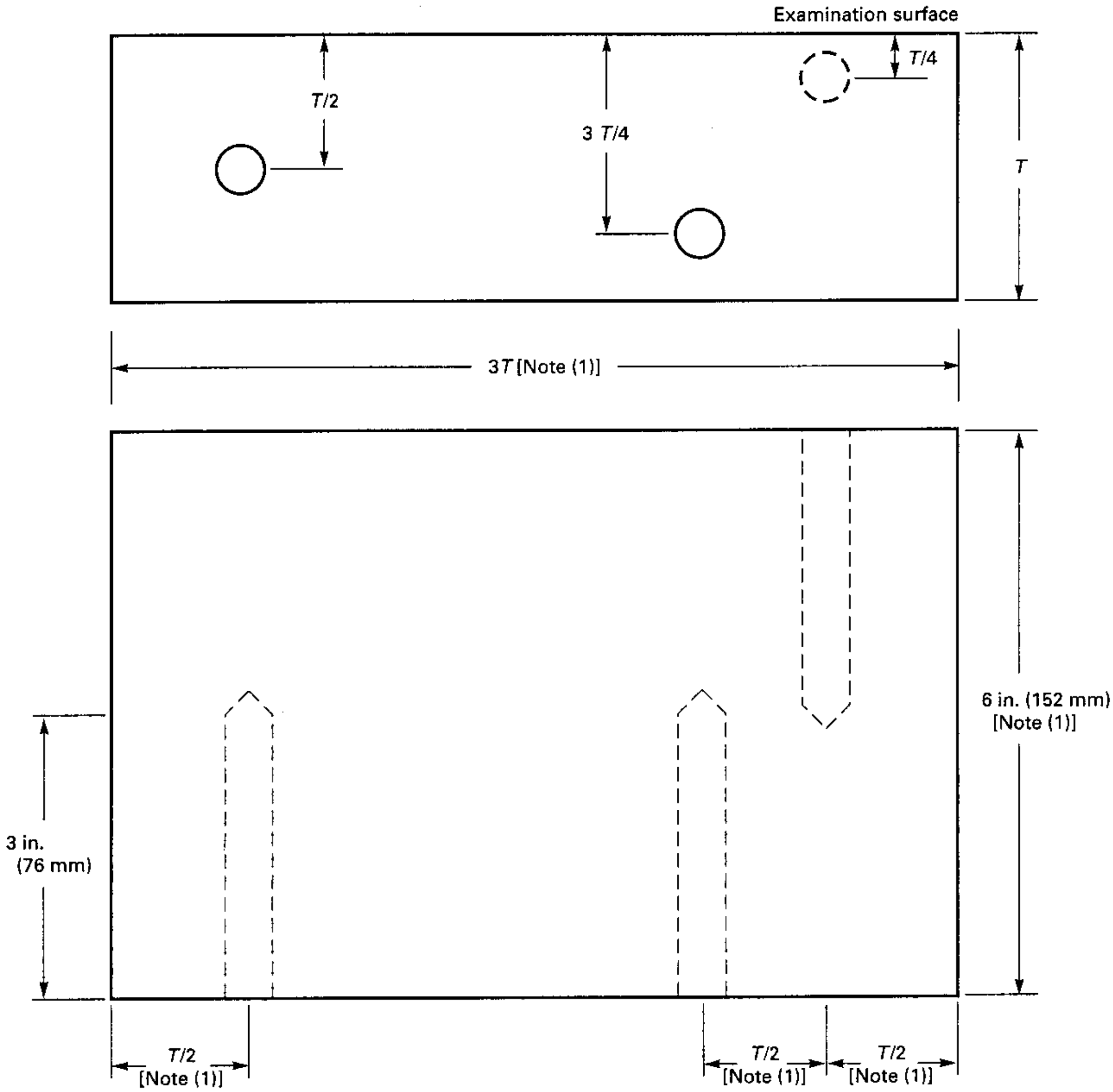
T-541.4.2.2 Calibration Method

(a) Straight Beam. The examination sensitivity adjustment shall be established as described in SA-609, exclusive of paragraph 7.3, on the calibration block described in T-541.4.2.1(a).

(b) Angle Beam. The examination sensitivity shall be established at 80% of full screen height using the side-drilled hole producing the largest response. The distance amplitude correction (DAC) curve shall be constructed by utilizing the responses from the side drilled hole reflectors in the angle beam calibration block [Fig. T-541.4.1.2(b)] covering the examination distance range in the casting to be examined.

T-541.4.3 Examination. The requirements for examination shall be in accordance with SA-609, and supplemented by (a) and (b) below.

(a) A supplementary angle beam examination shall be performed on castings or areas of castings where a back reflection cannot be maintained during the



GENERAL NOTE:
HOLES: Drilled and reamed essentially parallel to the examination surface. The tolerance on hole diameter shall be ± $\frac{1}{32}$ in. (0.8 mm). The tolerance on location through the thickness shall be ± $\frac{1}{8}$ in. (3.2 mm).

Material Thickness T	Diameter D	Holes Required
$\frac{1}{2}$ in. (13 mm) through 2 in. (51 mm)	$\frac{1}{4}$ in. (6 mm)	$T/2$
Greater than 2 in. (51 mm)	$\frac{3}{8}$ (10 mm)	$T/4$, $T/2$, and $3T/4$

NOTE:
(1) Minimum.

FIG. T-541.4.1.2(b) ANGLE BEAM CALIBRATION BLOCK

TABLE T-541.5.1
FLAT BOTTOM HOLE REQUIREMENTS

$D = d \pm 1$ in.	(25 mm)	Flat Bottom Hole Diam. $\pm 1/32$ in.	(0.8 mm)
Up to 1 in.	(25 mm)	1/16 in.	(1.6 mm)
Over 1 to 2 in.	(25 mm to 51 mm)	1/8 in.	(3.2 mm)
Over 2 to 3 in.	(51 mm to 76 mm)	3/16 in.	(4.8 mm)
Over 3 to 4 in.	(76 mm to 102 mm)	5/16 in.	(7.9 mm)
Over 4 in.	(102 mm)	3/8 in.	(9.5 mm)

GENERAL NOTE:
Flat bottom hole machined to a minimum depth of 1/2 in. (13 mm) parallel to the transducer contact surface.

TABLE T-541.5.2
CALIBRATION BLOCK DESIGNATION PER LENGTH AND HOLE LOCATION

Block Designation	Block Length L	Flat Bottom Hole Location L
A	$\ell/8$ + hole depth	$D/4$ of block end
B	$\ell/2$ + hole depth	Center line of block end
C	$\ell/4$ + hole depth	Center line of block end

GENERAL NOTE: A tolerance of ±5% may be applied.

straight beam examination, or where the angle between the front and back surfaces of the castings exceeds 15 deg.

(b) The requirements for extent of examination and acceptance criteria shall be as required by the referencing Code Section.

T-541.5 Bolting Material. Procedures used for ultrasonic examination of bolting material bolts, studs, and nuts shall conform to the requirements of SA-388 as modified by the following subparagraphs. Calibration blocks in accordance with Tables T-541.5.1 and T-541.5.2 shall be used for straight beam calibration. Tables T-541.5.1 and T-541.5.2 show relationships between examined material diameter d, length ℓ, and calibration block diameter D, and length L. Flat bottom holes shall be as shown in Fig. T-541.5.1 drilled a minimum of $1\frac{1}{2}$ in. (38 mm) deep in the axial direction of the block.

Calibration block material and examination surface finish shall be the same or equivalent to the bolting under examination.

T-541.5.1 Straight Beam, Radial Scan. Bolting materials shall be examined radially prior to threading. The examination shall be in accordance with the following.

(a) Technique. The examination shall be performed using pulse-echo, straight beam equipment with the contact or immersion technique.

(b) Calibration. The sensitivity shall be established using the reflection indication from the side of the hole in calibration block A, at the radial metal paths of $D/4$ and $3D/4$. Select the hole indication at the metal path which gives the greatest amplitude and set the gain control so that this indication is 80%±5% of full screen height. Without changing the instrument controls, obtain maximum amplitudes from the other metal path. Mark the indication amplitudes on the cathode ray tube, connect the adjacent points and extend the DAC to cover the range of examination.

(c) Examination. Scanning shall be performed helically or circumferentially in overlapping paths so as to cover the entire accessible cylindrical surface of the bar.

(d) Evaluation. Any imperfection which causes an indication in excess of 20% of DAC shall be investigated to the extent that it can be evaluated in terms of the acceptance standards of the referencing Code Section.

T-541.5.2 Straight Beam, Axial Scan. Bolting materials shall be examined axially before or after threading. The examination shall be conducted in accordance with the following.

(a) Technique. The examination shall be performed from both end surfaces of the material using pulse-echo, straight beam equipment with the contact or immersion technique.

(b) Calibration. The sensitivity shall be adjusted to give an 80% of full screen amplitude from the flat bottom hole in the block which gives the highest amplitude. Mark this amplitude and the amplitude of the flat bottom hole in the lower amplitude block on the screen, and connect the two marks with a straight line extending to the entry surface indication. This is the DAC line. If the lower amplitude block gives less than 20% of full screen amplitude, prepare an $\ell/4$ + hole depth block and construct two DAC lines to cover the examination metal path range. This is accomplished by setting the sensitivity to give an 80% of full screen amplitude from the flat bottom hole in the $\ell/8$ or $\ell/4$ block which gives the higher amplitude. Mark this amplitude and the amplitude of the lower amplitude block on the screen and connect the two marks with a straight line extending to the entry surface indication. Record the sensitivity setting which will be used in

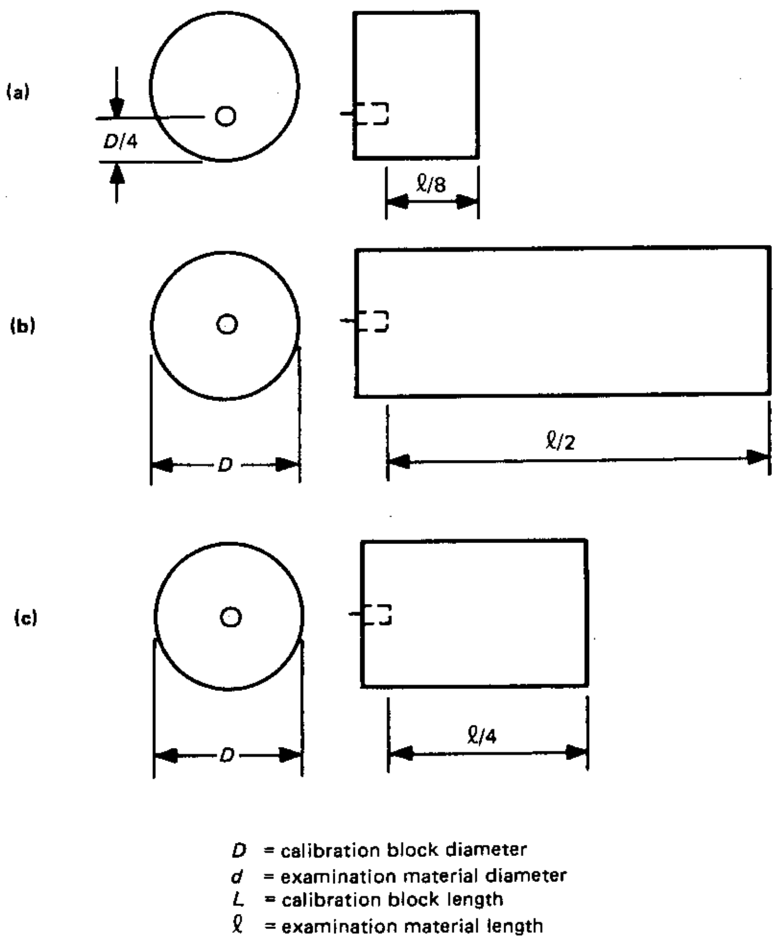


FIG. T-541.5.1 STRAIGHT BEAM (FBH) CALIBRATION BLOCK

the examination of the end quarters of length of the bolting material. Next set the sensitivity to give an 80% of full screen amplitude from the flat bottom hole in the $\ell/4$ or $\ell/2$ block which gives the higher amplitude. Mark this amplitude and the amplitude of the lower amplitude block on the screen and connect the two marks with a straight line. Record the sensitivity setting which will be used in the examination of the two middle quarters of length of the bolting material.

(c) Examination. Surface preparation — both end surfaces of the bolting material shall be flat and normal to the bolt axis. Record all indications exceeding 20% DAC in the quarter of length applicable to the sensitivity setting.

(d) Evaluation. Any reflector which causes an indication in excess of 20% of DAC shall be investigated to the extent that it can be evaluated in terms of the acceptance standards of the referencing Code Section.

T-541.5.3 Inservice Examination of Bolts and Studs

T-541.5.3.1 When inservice examination of bolts and studs is specified by the referencing Code Section, the examination shall be performed in accordance with Appendix L of Article 4.

T-541.5.3.2 For materials with diameters 2 in. and greater, basic calibration blocks shall have reflectors in accordance with Appendix L.

T-541.5.3.3 For bolts and studs less than 2 in. (51 mm) in diameter, a calibration block shall be made to the requirements of Appendix L, except for the size of the reflectors. The reflector area shall be established as one thread depth for the threads used on the bolt or stud. The area of the reflector is determined by the depth of a straight notch and the resulting length of the notch. Any of the types of notches illustrated in

Article 4, Appendix L, Fig. L-13-1 may be used as long as the area does not exceed that calculated for a straight notch one thread depth deep.

T-541.5.3.4 Any discontinuity which causes an indication in excess of that produced by the calibration reflector shall be investigated. The size and location of all such reflectors shall be evaluated in accordance with the acceptance standards of the referencing Code Section.

T-542 Welds

These paragraphs describe the requirements for ultrasonic examination of full penetration welds in wrought (rolled, drawn, forged, or extruded) and cast materials.

These requirements are established for the ultrasonic detection, location, and evaluation of ultrasonic reflectors within the weld, heat affected zone, and adjacent material. The two general examination classifications are:

(a) welds in ferritic product forms other than pipe;

(b) ferritic welds in ferritic pipe.

For austenitic and high nickel alloy welds, see T-542.8.5.

T-542.1 Equipment. The requirements for equipment shall be in accordance with T-530.

T-542.2 Calibration

T-542.2.1 Basic Calibration Block(s). The basic calibration reflectors shall be used to establish a primary reference response of the equipment. The basic calibration reflectors may be located either in the component material or in a basic calibration block. Where the block thickness ±1 in. (25 mm) spans two of the weld thickness ranges shown in Fig. T-542.2.1, the block's use shall be acceptable in those portions of each thickness range covered by 1 in. (25 mm).

T-542.2.1.1 Basic Calibration Block Material

(a) Block Selection. The material from which the block is fabricated shall be of the same product form, and material specification or equivalent P-Number grouping as one of the materials being examined. For the purposes of this paragraph, P-Nos. 1, 3, 4, and 5 materials are considered equivalent. For calibration blocks for dissimilar metal welds, the material selection shall be based on the material on the side of the weld from which the examination will be conducted: if the examination will be conducted from both sides, calibration reflectors shall be provided in both materials. Where two or more base material thicknesses are involved, the calibration block thickness shall be determined by the average thickness of the weld.

(b) Clad. Where the component material is clad, the block shall be clad by the same welding procedure as the production part. Where the automatic method is impractical, deposition of clad shall be by the manual method. It is desirable to have component materials which have been clad before the drop outs or prolongations are removed.

(c) Heat Treatment. The calibration block shall receive at least the minimum tempering treatment required by the material specification for the type and grade, and also a postweld heat treatment of at least 2 hr, if the calibration block contains weld(s) other than cladding.

(d) Surface Finish. The finish on the surfaces of the block shall be representative of the surface finishes on the components.

(e) Block Quality. The calibration block material shall be completely examined with a straight beam search unit. Areas that contain an indication exceeding the remaining back reflection shall be excluded from the beam paths required to reach the various calibration reflectors.

T-542.3 Calibration Reflectors

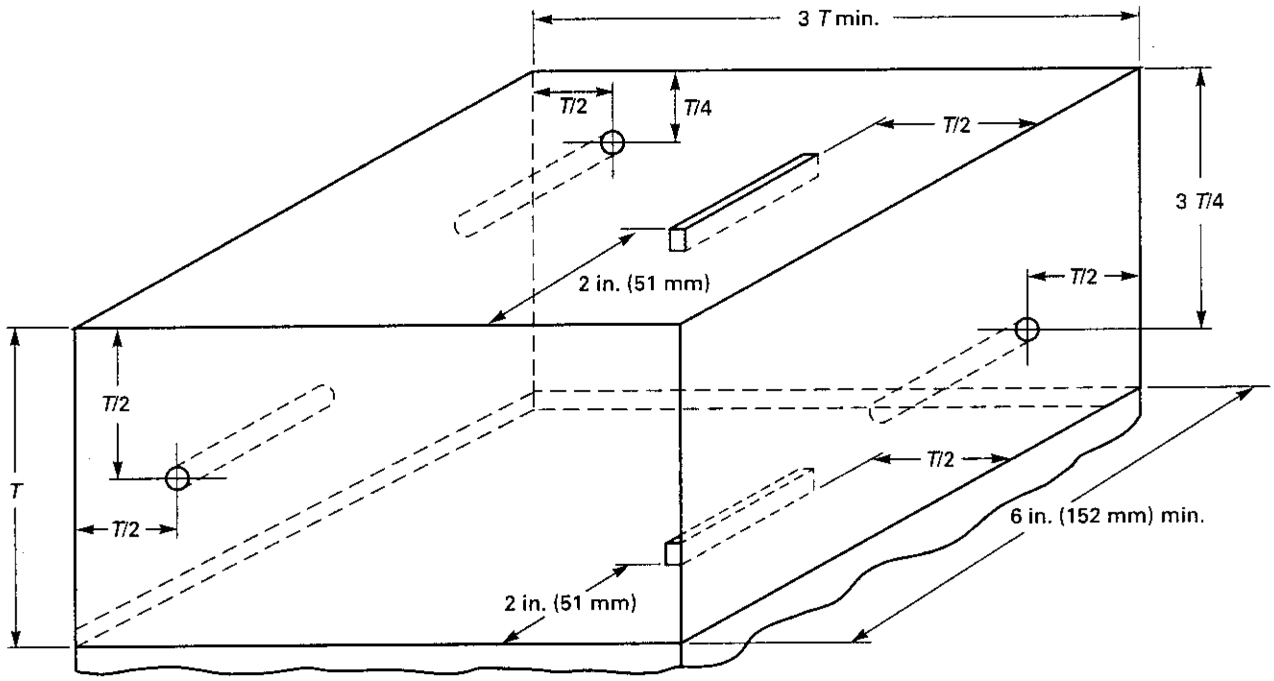
T-542.3.1 Basic Calibration Reflectors. The calibration reflectors are specified in T-542.2.1 and T-542.8.1.2.

T-542.3.2 Additional Reflectors. Additional reflectors may be installed; these reflectors shall not interfere with establishing the primary reference.

T-542.3.3 Calibration Block Configuration. Calibration block configuration requirements are specified in T-542.2.1 and T-542.8.1.1.

T-542.3.4 Materials With Diameters Greater Than 20 in. (508 mm). For examinations in materials where the examination surface diameter is greater than 20 in. (508 mm), a block of essentially the same curvature, or alternatively, a flat basic calibration block, shall be used.

T-542.3.5 Materials With Diameters 20 in. (508 mm) and Less. The basic calibration block shall be curved for materials with diameters 20 in. (508 mm) and less. Except where otherwise stated in this Article, a single curved basic calibration block may be used to calibrate the examination on surfaces in the range of curvature from 0.9 to 1.5 times the basic calibration block diameter. For example, an 8 in. (203 mm) diameter curved block may be used to calibrate the examination on surfaces in the range of curvature from 7.2 in. to



Weld thickness, t, in. (mm)	Basic Calibration Block Thickness, T, in. (mm)	Hole Diameter, in. (mm)	Notch Size, in. (mm)
1 or less (25 or less)	$\frac{3}{4}$ or t (19 or t)	$\frac{3}{32}$ (2.4)	Width = $\frac{1}{8}$ to $\frac{1}{4}$ (3.2 to 6.4)
Over 1 through 2 (25 through 51)	$1\frac{1}{2}$ or t (38 or t)	$\frac{1}{8}$ (3.2)	
Over 2 through 4 (51 through 102)	3 or t (76 or t)	$\frac{3}{16}$ (4.8)	Depth = 2% T or 0.04 whichever is greater, into the base metal (2% T or 0.1, whichever is greater, into the base metal.)
Over 4 through 6 (102 through 152)	5 or t (127 or t)	$\frac{1}{4}$ (6.4)	
Over 6 through 8 (152 through 203)	7 or t (178 or t)	$\frac{5}{16}$ (7.9)	
Over 8 through 10 (203 through 254)	9 or t (230 or t)	$\frac{3}{8}$ (9.5)	
Over 10 (254)	$t \pm 1$ ($t \pm 25$)	[Note (1)]	Length = 2 min. (51 min.)

GENERAL NOTES:
(a) Holes shall be drilled and reamed a minimum of $1\frac{1}{2}$ in. (38 mm) deep, essentially parallel to the examination surface.
(b) Alternatively, the block may be constructed as shown in Article 4, Appendix J, Fig. J-10.
(c) Curved surfaces: for curved surfaces, two curved blocks, one for each representative curvature; or two sets of calibration reflectors oriented 90 deg. from each other shall be used.
(d) Notches may be provided as required.
(e) The tolerance for hole diameter shall be $\pm \frac{1}{32}$ in. The tolerance on notch depth shall be +10 and −20%. The tolerance on hole location through the thickness shall be $\pm \frac{1}{8}$ in. (3.2 mm).

NOTE:
(1) For each increase in weld thickness of 2 in. (51 mm) or fraction thereof over 10 in. (254 mm), the hole diameter shall increase $\frac{1}{16}$ in. (1.6 mm).

FIG. T-542.2.1 BASIC CALIBRATION BLOCK

12 in. (183 mm to 305 mm) diameter. The curvature range from 0.94 in. to 20 in. (25 mm to 508 mm) diameter requires 6 block curvatures as indicated in Fig. T-542.3.5 for any thickness range.

T-542.3.6 As an alternative to the requirements in T-542.3.4 when examining from the convex surface by the straight beam contact technique, Appendix A may be used.

T-542.4 System Calibration

T-542.4.1 General Requirements. Calibration shall include the complete ultrasonic examination system.

T-542.4.2 Calibration Measurements. Each calibration shall be performed from the surface (clad or unclad) corresponding to the surface of the component from which the examination will be performed.

T-542.4.3 Techniques. Article 4, Appendices B and C, gives general techniques for both angle beam and straight beam calibrations. Other techniques may be used.

T-542.4.4 Angle Beam Calibration. As applicable, the calibration shall provide the following measurements (Article 4, Appendix B contains a general technique):

(a) sweep range calibration;

(b) distance–amplitude correction;

(c) position calibration;

(d) echo amplitude measurement from the surface notch in the basic calibration block.

When an electronic distance–amplitude correction device is used, the primary reference responses from the basic calibration block shall be equalized over the distance range to be employed in the examination. The response equalization line shall be at a screen height of 40% to 80% of full screen height.

T-542.4.5 Straight Beam Calibration. The calibration shall provide the following measurements (Article 4, Appendix C gives a general technique):

(a) sweep range calibration;

(b) distance–amplitude correction.

When an electronic distance–amplitude correction device is used, the primary reference response shall be equalized on the basic calibration block at a screen height between 40% and 80% of full screen height over the distance range to be employed in the examination.

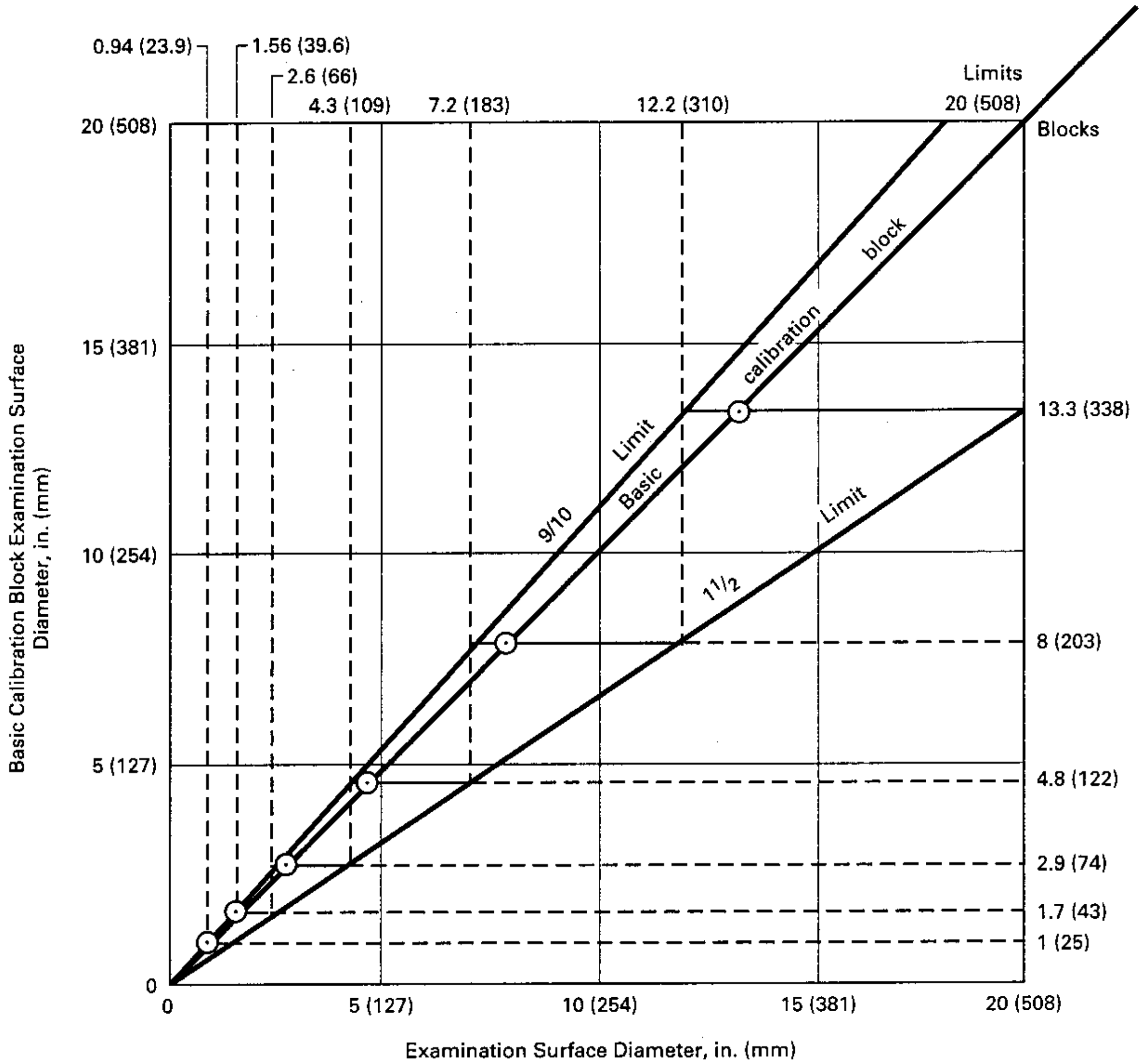
T-542.4.6 Calibration Check on Basic Calibration Block. When any part of the examination system is changed, a calibration check shall be made on the basic calibration block to verify that $\frac{1}{4}T$, $\frac{1}{2}T$, and $\frac{3}{4}T$ points on the sweep and distance amplitude correction values recorded satisfy the requirements of T-542.5. Where original calibration data exist for the part of the system replaced, a check as permitted in T-542.4 may be used.

T-542.4.7 Calibration Check on Basic Calibration Block or Simulator Check. A calibration check on at least one of the basic reflectors in the basic calibration block or a check using a simulator shall be made at the finish of each examination or series of similar examinations, every 4 hr during the examination, and when examination personnel (except for automated equipment) are changed. The sweep and distance amplitude correction values recorded shall satisfy the requirements of T-542.5.

T-542.4.8 Simulator Check. Any simulator checks that are used shall be correlated with the original calibration on the basic calibration block during the original calibration. The simulator checks may use different types of calibration reflector or block (such as IIW) and/or electronic simulation. However, the simulation used shall be completely identifiable on the calibration sheet(s). The simulator check shall be made on the entire examination system. The entire system does not have to be checked in one operation; however, for its check, the search unit shall be connected to the ultrasonic instrument and checked against a calibration reflector. Accuracy of the simulator checks shall be confirmed, using the basic calibration block, at the conclusion of each period of extended use, or every 3 months, whichever is less. The requirements for calibration confirmation of T-542.5 and T-542.5.1 shall be met.

T-542.5 Calibration Confirmation. Calibration (T-542.4.3) shall be performed prior to use of the system in the thickness range under examination. A calibration check shall verify the sweep range calibration and distance–amplitude correction [T-542.4.4(a) or T-542.4.5(a)] as defined in T-542.4.1.

T-542.5.1 Sweep Range Correction. If a point on the DAC curve has moved on the sweep line more than 10% of the sweep reading or 5% of full sweep, whichever is greater, correct the sweep range calibration and note the correction in the examination record. If reflectors are recorded on the data sheets, those data sheets shall be voided and a new calibration shall be recorded. All recorded indications since the last valid calibration or calibration check shall be reexamined with the corrected calibration and their values shall be changed on the data sheets.



GENERAL NOTES:
(a) Plot examination surface of basic calibration block on diagonal (45 deg) line.
(b) Draw horizontal line through that point from the 9/10 to the $1^1/_2$ limit line.
(c) The ends of this line read on the horizontal scale give the range of examination surface diameters which may be examined with a system calibrated on this block.
(d) Thickness range requirements shall also be satisfied.

FIG. T-542.3.5 RATIO LIMITS FOR CURVED SURFACES

T-542.5.2 DAC Correction. If a point on the distance–amplitude correction (DAC) curve has decreased 20% or 2 dB of its amplitude, all data sheets since the last calibration or calibration check shall be marked void. A new calibration shall be made and recorded and the area covered by the voided data shall be reexamined. If any point of the distance–amplitude correction (DAC) curve has increased more than 20% or 2 dB of its amplitude, all recorded indications since the last valid calibration or calibration check shall be reexamined with the corrected calibration and their values shall be changed on the data sheets.

T-542.6 Welds in Wrought and Cast Ferritic Product Forms, Excluding Pipe

T-542.6.1 Basic Calibration

T-542.6.1.1 Basic Calibration Block. The basic calibration block shall be as specified in T-542.2.1, and shall use side-drilled holes as calibration reflectors. See Fig. T-542.2.1.

T-542.6.1.2 Angle Beam Calibration. Angle beam calibrations shall be performed as described in Article 4, Appendix B, supplemented as follows:

T-542.6.1.3 Frequency. The nominal frequency shall be 2.25 MHz unless variables such as production material grain structure require the use of other frequencies to assure adequate penetration or better resolution.

T-542.6.1.4 Beam Angle. An angle shall be selected as appropriate for the configuration being examined.

T-542.6.1.5 Distance–Amplitude Correction (DAC) Exemption. A DAC is not required where the examination is limited to one-half V-path in a material less than 1 in. thick, in which case the amplitude level from a single calibration reflector shall be used.

T-542.6.1.6 Straight Beam Calibration. Calibration and straight beam examination shall be performed in accordance with Article 4, Appendix C, supplemented as follows.

T-542.6.1.7 Frequency. The nominal frequency shall be 2.25 MHz unless variables such as production material grain structure require the use of other frequencies to assure adequate penetration or better resolution.

T-542.7 Examination of Welds

T-542.7.1 Surface Preparation

T-542.7.1.1 Base Metal. The base metal on each side of the weld shall be free of weld spatter, surface irregularities, or foreign matter that might interfere with the examination.

T-542.7.1.2 Weld Metal. Where the weld surface interferes with the examination, the weld shall be prepared as needed to permit examination.

T-542.7.2 Scanning

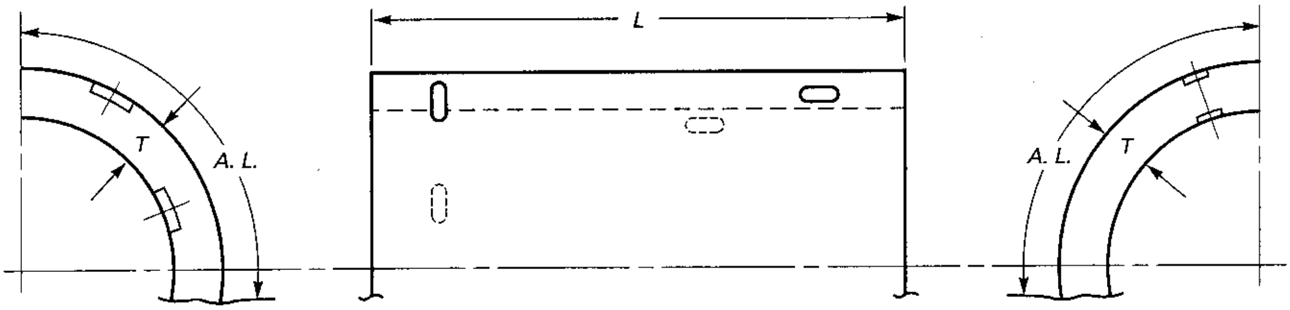
T-542.7.2.1 Straight Beam. The scanning of the adjacent base metal shall be performed to detect reflectors that might affect interpretation of angle beam results, and is not to be used as an acceptance-rejection examination. Locations and areas of such reflectors shall be recorded.

T-542.7.2.2 The weld and base metal shall be scanned, where required by the referencing Code Section to the extent possible with the straight beam search unit. The scanning shall be performed at a gain setting of at least two times the primary reference level. Evaluation shall be performed with respect to the primary reference level.

T-542.7.2.3 Angle Beam Scanning for Reflectors Oriented Parallel to the Weld. The angle beam shall be directed at approximate right angles to the weld axis from two directions where possible. The search unit shall be manipulated so that the ultrasonic energy passes through the required volumes of weld and adjacent base metal. The scanning shall be performed at a gain setting at least two times the primary reference level. Evaluation shall be performed with respect to the primary reference level.

T-542.7.2.4 Angle Beam Scanning for Reflectors Oriented Transverse to the Weld. The angle beam shall be directed essentially parallel to the weld axis. The search unit shall be manipulated so that the angle beam passes through the required volumes of weld and adjacent base metal specified by the referencing Code Section. The scanning shall be performed at a gain setting at least two times the primary reference level. Evaluation shall be performed with respect to the primary reference level. The search unit shall be rotated 180 deg. and the examination repeated.

T-542.7.2.5 Evaluation. Any imperfection which causes an indication in excess of 20% DAC shall be investigated to the extent that it can be evaluated in terms of the acceptance standards of the referencing Code Section.



Typical Block Dimensions

Length L 8 in. *or* 8T, whichever is greater

Minimum Arc Length $A.L.$
(1) for O.D. or 4 in. (102 mm) or less: 270 deg.
(2) for O.D. greater than 4 in. (102 mm): the greater of 3T or 8 in. (203 mm)

Specific Notch Dimensions

Length L — 1 in. (25 mm) minimum

Depth D — 10% T with tolerance D $^{+10\%}_{-20\%}$ of depth

Width — $^1/_8$ in. to $^1/_4$ in. (3.2 mm to 6.4 mm)
Location — not closer than T from any block edge

FIG. T-542.8.1.1 ANGLE BEAM CALIBRATION (PIPE WELDS)

T-542.8 Ferritic Welds in Ferritic Pipe

T-542.8.1 Basic Calibration

T-542.8.1.1 Basic Calibration Block (See Fig. T-542.8.1.1). The basic calibration block for weldments shall be a section of pipe of the same nominal size, schedule, heat treatment, and material specification or equivalent P-Number grouping as one of the materials being examined. For the purposes of this paragraph, P-Nos. 1, 3, 4, and 5 materials are considered equivalent. The block size and reflector locations shall be adequate to perform calibration for the beam angles used. The surface finish of the calibration block shall be representative of the surface finish of the piping.

T-542.8.1.2 Basic Calibration Reflectors. The basic calibration reflectors shall be longitudinal and with circumferential notches on both the inner and outer surfaces. The sizes and locations of the calibration reflectors are shown in Fig. T-542.8.1.1.[1]

T-542.8.2 Angle Beam Calibration

T-542.8.2.1 Frequency. The nominal frequency shall be 2.25 MHz, unless attenuation or a need for greater resolution makes some other frequency more suitable.

T-542.8.2.2 The nominal beam angle of 45 deg. shall generally be used but other angles may be used where appropriate for the configuration being examined.

T-542.8.2.3 Distance–Amplitude Correction (DAC). A DAC curve is required for all pipe welds. For examination of a full wall thickness, the notches shall be used as calibration reflectors. The angle beam shall be directed toward the calibration reflector that yields the maximum response, setting the instrument adjustment to yield 80% of screen height. The search unit shall then be manipulated, without changing instrument settings, to obtain the maximum responses from the calibration reflectors at the distance increments necessary to generate a 3-point DAC curve.

T-542.8.2.4 Selection of Calibration Reflectors. A side-drilled hole may be used for initial acceptance of a pipe weld, provided that it can be demonstrated that the hole calibration produces a sensitivity equal to or greater than the notch calibration.

T-542.8.2.5 Straight Beam Calibration. Straight beam examination, when required by the refer-

[1] When side-drilled holes are to be used for calibration, the block shall be as shown in Fig. T-542.2.1 (see T-542.8.2.5).

encing Code Section, or, if needed to evaluate an angle beam indication, shall be calibrated on the side drilled holes in the basic calibration block. When required, the straight beam calibration shall be performed to the requirements of Article 4, Appendix C.

T-542.8.3 Examination of Pipe Weldments

T-542.8.3.1 Surface Preparation. Surface preparation shall be performed to the requirements of T-542.7.1.

T-542.8.4 Scanning of Pipe Weldments

T-542.8.4.1 Straight Beam. When straight beam scanning is required, it shall be performed according to the requirements of T-542.7.2.1.

T-542.8.4.2 Angle Beam. Angle beam scanning of pipe welds shall be performed according to the requirements of T-542.7.2.3 and T-542.7.2.4.

T-542.8.4.3 Evaluation. Any imperfection which causes an indication in excess of 20% DAC shall be investigated to the extent that it can be evaluated in terms of the acceptance standards of the referencing Code Section.

T-542.8.5 Austenitic and High Nickel Alloy Welds

T-542.8.5.1 Discussion. Ultrasonic examination of austenitic and high nickel alloy welds is usually more difficult than in ferritic materials, because of the wide variations that may occur in the acoustic properties of austenitic and high nickel alloy welds, even those in alloys of the same composition, product form, and heat treatment. It may, therefore, be necessary to modify and/or supplement the provisions of this Article in accordance with T-150(a) when examining such welds.

T-543 Cladding

The pulse-echo ultrasonic techniques described in these paragraphs shall be used where ultrasonic examination of weld metal overlay cladding is required by a referencing Code Section. Examination of roll bonded and explosive clad plate shall be performed in accordance with SA-578/SA-578M when required by a referencing Code Section.

The techniques described herein shall be used for examination of weld deposited cladding. Technique One shall be used to examine for bond and clad flaw indications or Technique Two shall be used to examine for lack of bond.

T-543.1 Equipment

T-543.1.1 Equipment for Technique One. Dual search units using an angled pitch-catch technique may be used. The included angle between the beam paths shall be such that the maximum sensitivity of the search unit is in the area of interest. The total transducer area shall not exceed $\frac{1}{2}$ sq in. (322 mm^2). A nominal frequency of 2.25 MHz shall be used; however, other frequencies may be used to achieve the necessary resolution.

T-543.1.2 Equipment for Technique Two. Straight beam search units with a maximum transducer area of 1 sq in. (645 mm^2) shall be used. A nominal frequency of 2.25 MHz shall be used; however, other frequencies may be used to achieve the necessary resolution.

T-543.1.3 Calibration Block for Technique One. A calibration block clad by the same welding procedure as the production part shall be used. The surface condition shall be representative of that of the production part. Either a side-drilled hole $\frac{1}{16}$ in. (1.6 mm) diameter by $1\frac{1}{2}$ in. (38 mm) minimum depth shall be drilled into the block at the clad interface, or a $\frac{1}{8}$ in. (3.2 mm) diameter flat bottomed hole shall be drilled through the base metal to the clad interface. The thickness of the base material shall be at least twice the thickness of the cladding. The calibration block is shown in Fig. T-543.2.

T-543.1.4 Calibration Block for Technique Two. For clad bond examination, a calibration block clad by the same welding procedure as the production part shall be used. The surface condition shall be representative of the cladding on the production part. A $\frac{3}{8}$ in. (9.5 mm) flat bottom hole shall be drilled to the weld overlay interface. This hole may be drilled from the base metal or weld overlay side. Other calibration reflectors may be used provided it is demonstrated that equal or greater sensitivity is attained. The thickness of the base material examined shall be within 1 in. (25 mm) of the calibration block thickness when examined from the base metal surface. The thickness of the base material on the calibration block shall be at least twice the thickness of the cladding, when examining from the clad surface.

T-543.2 Calibration

T-543.2.1 Calibration for Technique One. Calibration shall be accomplished by placing the search unit on the clad surface of the calibration block and manipulating the search unit for the maximum response from the calibration hole. The gain control shall be

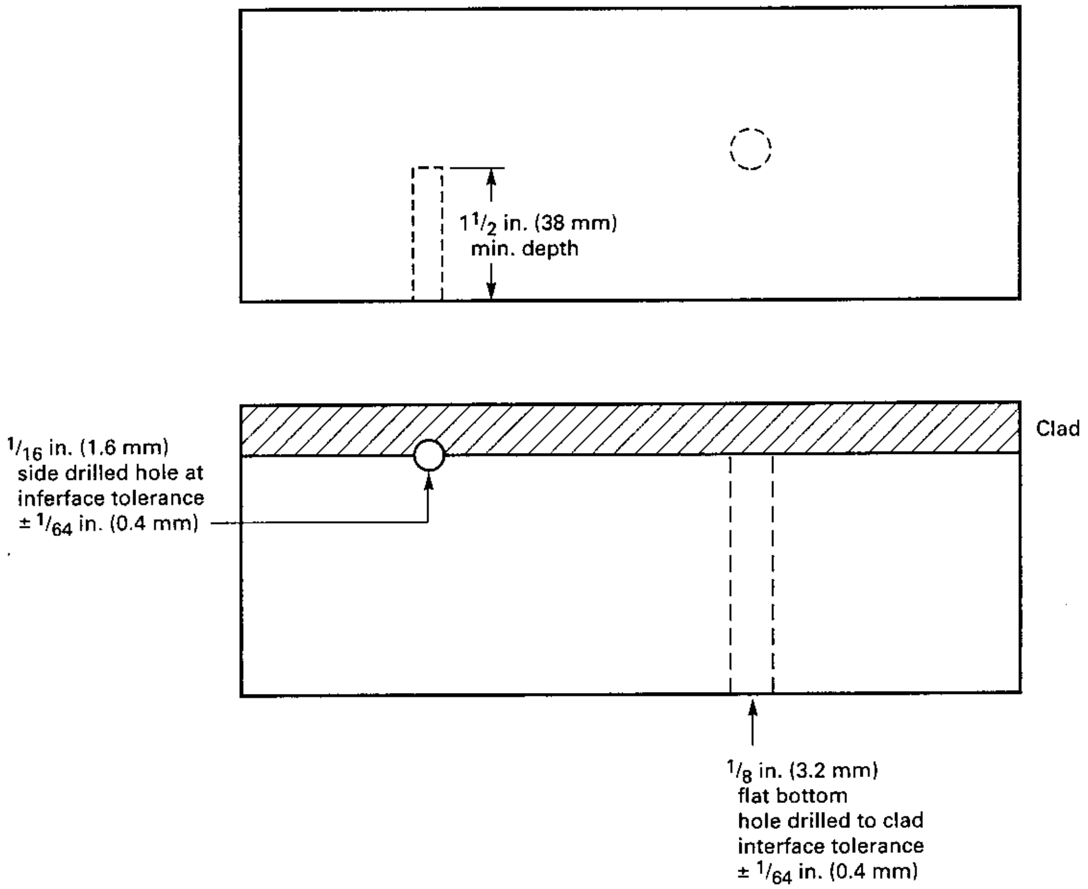


FIG. T-543.2 CALIBRATION BLOCK FOR TECHNIQUE ONE

set so that this response is 80% ±5% of full screen. This is primary reference level.

T-543.2.2 Calibration for Technique Two. Calibration shall be accomplished by placing the search unit on the calibration block on the side opposite from which the hole was drilled. The search unit shall be manipulated for the maximum response of the first resolvable indication from the bottom of the calibration hole. The gain shall be set so that this response is 80% ±5% of full screen. This shall be the primary reference level.

T-543.3 Examination

T-543.3.1 Technique One

(a) Examination Area. The entire clad surface shall be examined where practical. The examination shall be performed with the plane separating the elements of the dual search unit parallel to the axis of the weld bead. Examination shall be performed from the clad surface.

(b) Scanning Sensitivity. Scanning shall be performed at the primary reference level.

(c) Evaluation. All indications shall be evaluated at the primary reference level.

(d) Scanning Direction. The clad surface shall be scanned by moving the search unit perpendicular to the weld direction.

T-543.3.2 Technique Two

(a) Examination Area. As required by the referencing Code Section.

(b) Scanning Sensitivity. Scanning shall be performed at a gain higher than the primary reference level.

(c) Scanning shall be performed on the clad surface when calibration is performed on the clad surface. Scanning shall be performed on the unclad surface when calibration is performed on the unclad surface.

(d) Evaluation. All indications shall be evaluated at the primary reference level.

01 **T-544 Thickness Measurement**

Procedures used for ultrasonic examination for thickness determination shall conform to the following standards in Article 23, as applicable:

(a) SE-114 Standard Practice for Ultrasonic Pulse-Echo Straight-Beam Examination by the Contact Method

(b) SE-797 Standard Practice for Measuring Thickness by Manual Contact Ultrasonic Method

T-544.1 Equipment. The requirements for equipment shall be in accordance with T-530, and supplemented as follows:

(a) Frequency-thickness measurements may be conducted at any frequency capable of resolving the thickness range to be measured.

(b) The thickness measurement shall be indicated by a cathode ray tube, meter, or digital display.

(c) Calibration block(s) of similar ultrasonic velocity, surface, shape, and finish shall be provided.

NOTE: Common practice for obtaining similar ultrasonic velocities is to use similar material and product form (either wrought or cast).

T-544.2 Calibration. The examination system shall be calibrated on at least 2, preferably 3, calibration thicknesses covering the thickness range to be measured. Measurement accuracy, as noted in SE-114, is dependent upon calibration accuracy.

T-544.3 Examination. The technique used will depend on the thickness, surface geometry, and condition of the workpiece, except that the linearity requirements of T-532 and T-533 are not applicable to thickness measurements. The measurement technique used, and the extent of examination, shall comply with the referencing Code Section.

T-580 EVALUATION

T-581 Examination Using DAC

For examination using a distance–amplitude correction curve (DAC), any reflector which causes an indication in excess of 20% of DAC shall be investigated to the extent that it can be evaluated in terms of the acceptance standards of the referencing Code Section.

T-582 Examination Using Other Than DAC

For examination using other than DAC, evaluate according to the requirements of the referencing Code Section.

T-590 REPORTS AND RECORDS

T-591 Examination Reports

A report of the examinations shall be made. The report shall include a record indicating the weld(s) or volume examined (this may be marked-up sketched), the location of each recorded reflector, and the identification of the operator who carried out each examination or part thereof as detailed in T-593.

T-592 Calibration Records

Instrument calibrations in accordance with T-530 shall be included in the ultrasonic calibration records. Ultrasonic examination system calibration requirements in accordance with T-534 and calibration block identity shall be included in the ultrasonic calibration records.

T-593 Examination Records

For each ultrasonic examination, the following information should be identified and recorded. The referencing Code Section shall be consulted for specific requirements.

(a) procedure;

(b) ultrasonic examination system (equipment);

(c) examination personnel identity and level;

(d) calibration sheet identity;

(e) identification and location of weld or volume scanned;

(f) surface from which examination is conducted;

(g) map or record of indications detected or areas clear;

(h) date and time examinations were performed;

(i) couplant;

(j) basic calibration block identification;

(k) surface condition;

(l) frequency;

(m) special equipment.

T-594 Evaluation Record

Records of any evaluations of indications shall be maintained and documented as required by the referencing Code Section.

ARTICLE 5
MANDATORY APPENDICES

APPENDIX I — SCREEN HEIGHT LINEARITY

To verify the ability of the ultrasonic instrument to meet the linearity requirement of T-532, position an angle beam search unit as shown in Fig. I-1 so that indications can be observed from both the $\frac{1}{2}$ and $\frac{3}{4}T$ holes in a basic calibration block. Adjust the search unit position to give a 2:1 ratio of amplitudes between the two indications, with the larger set at 80% of full screen height. Without moving the search unit, adjust sensitivity (gain) to successively set the larger indication from 100% to 20% of full screen height, in 10% increments (or 2 dB steps if a fine control is not available), and read the smaller indication at each setting. The reading must be 50% of the larger amplitude, within 5% of full screen height. The settings and readings must be estimated to the nearest 1% of full screen. Alternatively, a straight beam search unit may be used on any calibration block, which will provide amplitude differences, with sufficient signal separation to prevent overlapping of the two signals.

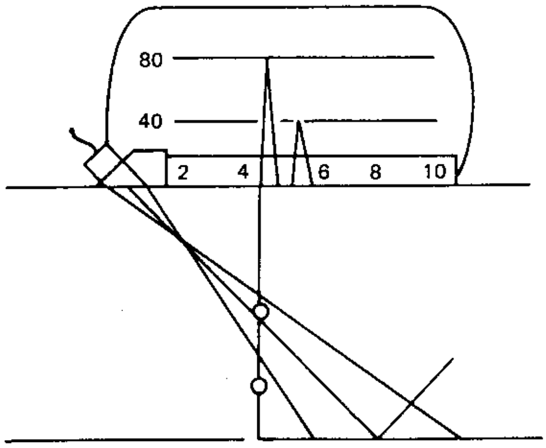


FIG. I-1 LINEARITY

APPENDIX II — AMPLITUDE CONTROL LINEARITY

To verify the accuracy of the amplitude control of the ultrasonic instrument, as required in T-533, position an angle beam search unit as shown in Fig. I-1 so that the indication from the $\frac{1}{2}T$ hole in a basic calibration block is peaked on the screen. With the increases and decreases in attenuation shown in the following table, the indication must fall within the specified limits. Other convenient reflectors from any calibration block may be used with angle or straight beam search units.

Indication Set at % of Full Screen	dB Control Change	Indication Limits % of Full Screen
80%	−6 dB	32 to 48%
80%	−12 dB	16 to 24%
40%	+6 dB	64 to 96%
20%	+12 dB	64 to 96%

The settings and readings must be estimated to the nearest 1% of full screen.

APPENDIX III — GLOSSARY OF TERMS FOR ULTRASONIC EXAMINATION

III-510 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definition of terms related to Ultrasonic Examination.

III-520 GENERAL REQUIREMENTS 01

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 Section I provides the definitions of terms listed in III-530(a).

(c) For general terms, such as *Interpretation, Flaw, Discontinuity, Evaluation*, etc., refer to Article 1, Mandatory Appendix I.

(d) Paragraph III-530(b) provides a list of terms and definitions, which are in addition to SE-1316 and are Code specific.

III-530 REQUIREMENTS

(a) The following SE-1316 terms are used in conjunction with this Article: A-scan; amplitude; angle beam; attenuation; attenuator; B-scan presentation; back reflection; base line; beam axis; beam spread; C-scan; collimator; compressional wave; couplant; critical angle; crystal; damping, search unit; decibel (dB); delayed sweep; Distance Amplitude Correction (DAC) curve; dual search unit; dynamic range; echo; examination system; far field; focused beam; frequency (fundamental); frequency (inspection); frequency (pulse repetition); gate; harmonics; holography (acoustic); immersion testing; impedance (acoustic); indication; initial pulse; interface; lamb wave; linearity (amplitude); linearity (time or distance); longitudinal wave; mode; mode conversion; near field; noise; normal incidence; plate wave; probe; pulse; pulse echo method; pulse length; pulse repetition rate; pulse tuning; radio frequency (RF) display; range; Rayleigh wave; reference block; reflector; reject; resolution; resonance method; saturation; scanning; scattered energy; scattering; Schlieren system; search unit; sensitivity; shadow; shear wave; signal-to-noise ratio; straight beam; sweep; test surface; through transmission technique; transducer; transverse wave; ultrasonic; ultrasonic response; ultrasonic spectroscopy; vee path; video presentation; water path; wave front; wave train; wedge.

(b) The following Code terms are used in conjunction with this Article:

axial direction — direction of sound beam parallel to component's major axis

calibration — correlation of the ultrasonic system response(s) with calibration reflector(s)

calibration reflector — a reflector with a dimensioned surface which is used to provide an accurately reproducible reference level

circumferential direction — direction of sound beam perpendicular to (cylindrical) component's major axis

clipping — see *reject*

computerized imaging — computer processed display or analysis and display of ultrasonic data to provide two- or three-dimensional images of reflectors

crack-tip diffraction — the edge wave emanating from a flaw that is insonified by an ultrasonic beam

CRT — cathode ray tube

dynamic calibration — calibration that is conducted with the search unit in motion, usually at the same speed and direction of the actual test examination

electric simulator — an electronic device that enables correlation of ultrasonic system response initially obtained employing the basic calibration block

image space — a computer selected volume of material being interrogated by the ultrasonic field

multiple back reflections — in ultrasonic straight beam examination, successive reflections between back and front surfaces of the material

oscillogram — common term for photograph of data displayed on CRT

piezoelectric element — crystal or polycrystal materials which when mechanically deformed, produce electrical charges, and conversely, when intermittently charged, will deform and produce mechanical vibrations

primary reference response (level) — the ultrasonic response from the basic calibration reflector at the specified sound path distance, electronically adjusted to a specified percentage of the full screen height

refraction — the angular change in direction of the ultrasonic beam as it passes obliquely from one medium to another, in which the waves have a different velocity

ringing time — the time that the mechanical vibrations of a piezoelectric element continue after the electrical pulse has stopped

simulation block — a reference block or other item in addition to the basic calibration block that enables correlation of ultrasonic system response initially obtained when using the basic calibration block

SAFT-UT — Synthetic Aperture Focusing Technique for ultrasonic testing

static calibration — calibration for examination wherein the search unit is positioned on a calibration block so that the pertinent reflectors can be identified and the instrumentation adjusted accordingly

time-of-flight — the time required for an ultrasonic pulse to travel from the transmitter to the receiver

ARTICLE 5
NONMANDATORY APPENDIX

APPENDIX A — ALTERNATE CALIBRATION BLOCK CONFIGURATION

Flat basic calibration blocks of various thicknesses may also be used to calibrate the examination of convex surface materials greater than 20 in. (508 mm) in diameter. An adjustment of receiver gain may be required when flat calibration blocks are used. The gain corrections apply to the far field portion of the sound beam.

TABLE A-10
TRANSDUCER FACTOR F_1 FOR VARIOUS ULTRASONIC TRANSDUCER DIAMETERS AND FREQUENCIES

U.S. Customary Units

Frequency MHz	Transducer Diameters, in. 0.25	0.5	0.75	1.0	1.125
	F_1, in.				
1.0	2.58	10.3	23.2	41.3	52.3
2.25	5.81	23.2	52.2	92.9	118
5.0	12.9	51.2	116	207	262
10.0	25.8	103	232	413	523

SI Units

Frequency MHz	Transducer Diameters, mm 6.4	13	19	25	29
	F_1, mm				
1.0	66	262	589	1 049	1 328
2.25	148	589	1 326	2 360	2 997
5.0	328	1 300	2 946	5 258	6 655
10.0	655	2 616	5 893	10 490	13 284

A-10 DETERMINATION OF GAIN CORRECTION

To determine the required increase in gain, the ratio of the material radius, R, to the critical radius of the transducer, R_c, must be evaluated as follows.

(a) When the ratio of R/R_c, the radius of curvature of the material R divided by the critical radius of the transducer R_c from Table A-10 and Fig. A-10(a), is equal to or greater than 1.0, no gain correction is required.

(b) When the ratio of R/R_c is less than 1.0, the gain correction must be obtained from Fig. A-10(b).

(c) *Example.* Material with a 10 in. (254 mm) radius (R) will be examined with a 1 in. (25 mm) diameter 2.25 MHz boron carbide faced search unit using glycerine as a couplant.

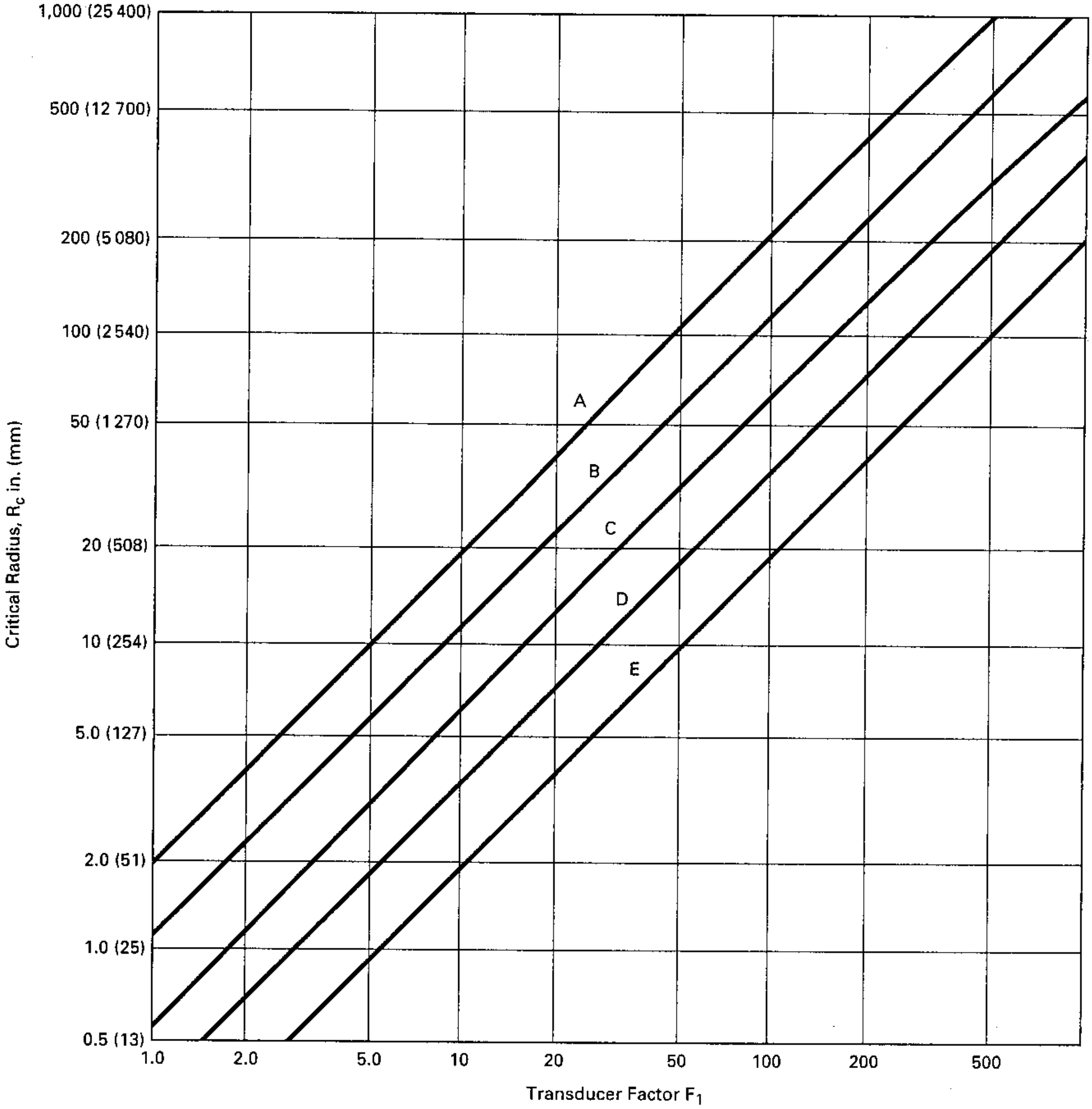
(1) Determine the appropriate transducer factor, F_1 from Table A-10; $F_1 = 93$.

(2) Determine the R_c from Fig. A-10(a); $R_c =$ 100 in.

(3) Calculate the R/R_c ratio; 10 in./100 in. (25 mm/254 mm) = 0.1.

(4) Using Fig. A-10(b), obtain the gain increase required; 12 dB.

This gain increase calibrates the examination on the curved surface after establishing calibration sensitivity on a flat calibration block.



Curve	Couplant	Transducer Wearface
A	Motor oil or water	Aluminum Oxide or Boron Carbide
B	Motor oil or water	Quartz
	Glycerine or syn. ester	Aluminum Oxide or Boron Carbide
C	Glycerine or syn. ester	Quartz
D	Motor oil or water	Plastic
E	Glycerine or syn. ester	Plastic

FIG. A-10(a) CRITICAL RADIUS R_C FOR TRANSDUCER/COUPLANT COMBINATIONS

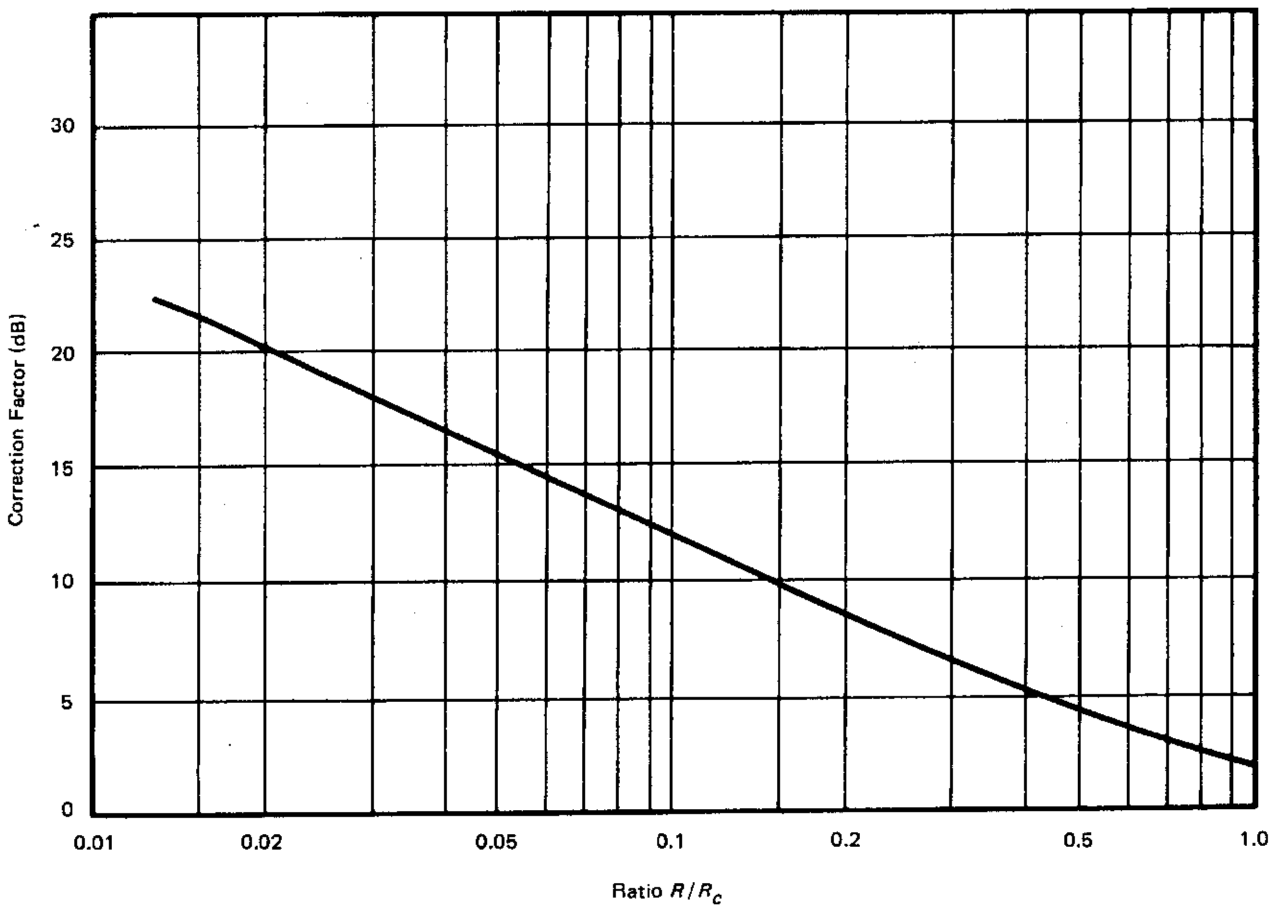


FIG. A-10(b) CORRECTION FACTOR (GAIN) FOR VARIOUS ULTRASONIC EXAMINATION PARAMETERS

ARTICLE 6

Figure

Table

Mandatory Appendix

ARTICLE 6
LIQUID PENETRANT EXAMINATION

T-600 SCOPE

The liquid penetrant examination method is an effective means for detecting discontinuities which are open to the surface of nonporous metals and other materials. Typical discontinuities detectable by this method are cracks, seams, laps, cold shuts, laminations, and porosity.

In principle, a liquid penetrant is applied to the surface to be examined and allowed to enter discontinuities. All excess penetrant is then removed, the part is dried, and a developer is applied. The developer functions both as a blotter to absorb penetrant that has been trapped in discontinuities, and as a contrasting background to enhance the visibility of penetrant indications. The dyes in penetrants are either color contrast (visible under white light) or fluorescent (visible under ultraviolet light).

T-610 REFERENCING DOCUMENTS

01 **T-610.1** When specified by the referencing Code Section, the liquid penetrant examination techniques described in this Article shall be used. The following SE Standard provides details that may be considered in the specific procedures used:

(a) SE-165 Standard Test Method for Liquid Penetrant Examination

T-610.2 The liquid penetrant method described in this Article shall be used together with Article 1, General Requirements.

T-610.3 Definitions of terms used in this Article are in Mandatory Appendix I of this Article.

T-620 GENERAL

01 T-621 Procedure Requirements

01 **T-621.1** Liquid penetrant examination shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable:

(a) the materials, shapes, or sizes to be examined, and the extent of the examination;

(b) type (number or letter designation if available) of each penetrant, penetrant remover, emulsifier, and developer;

(c) processing details for pre-examination cleaning and drying, including the cleaning materials used and minimum time allowed for drying;

(d) processing details for applying the penetrant: the length of time that the penetrant will remain on the surface (dwell time), and the temperature of the surface and penetrant during the examination if outside 50°F (10°C) to 125°F (52°C) range;

(e) processing details for removing excess penetrant from the surface, and for drying the surface before applying the developer;

(f) processing details for applying the developer, and length of developing time before interpretation;

(g) processing details for post-examination cleaning.

T-621.2 Procedure Revision. A revised procedure may be required:

(a) whenever a change or substitution is made in the type or family group of penetrant materials (including developers, emulsifiers, etc.) or in the processing techniques;

(b) whenever a change or substitution is made in the type of precleaning materials or processes;

(c) for any change in part processing that can close surface openings of discontinuities or leave interfering deposits, such as the use of grit blast cleaning or acid treatments.

T-630 EQUIPMENT

T-631 Penetrant Materials

The term *penetrant materials,* as used in this Article, is intended to include all penetrants, emulsifiers, solvents or cleaning agents, developers, etc., used in the examina-

tion process. The descriptions of the liquid penetrant classifications and material types are provided in SE-165.

T-640 REQUIREMENTS

T-641 Control of Contaminants

The user of this Article shall obtain certification of contaminant content for all liquid penetrant materials used on nickel base alloys, austenitic stainless steels, and titanium. These certifications shall include the penetrant manufacturers' batch numbers and the test results obtained in accordance with (a) and (b) below. These records shall be maintained as required by the referencing Code Section.

(a) When examining nickel base alloys, all materials shall be analyzed individually for sulfur content as follows.

(1) An individual sample of the penetrant materials with exception of cleaners shall be prepared for analysis by heating 50 g of the material in a 150 mm nominal diameter glass Petri dish at a temperature of 194°F to 212°F (90°C to 100°C) for 60 min.

PRECAUTION: Provide adequate ventilation to dissipate the emitted vapor.

(2) Analysis of the residue shall be as follows: If the residue is less than 0.0025 g, the material is acceptable without further analysis. If the residue is 0.0025 g or more, the procedure shown in (a)(1) above shall be repeated and the residue analyzed in accordance with SD-129 or SD-1552. Alternately, the material may be decomposed in accordance with SD-129 and analyzed in accordance with SD-516 Method B. The sulphur content shall not exceed 1% of the residue by weight.

(3) An individual sample of cleaner/remover material shall be prepared for analysis by heating 100 g of the material in a 150 mm nominal diameter glass Petri dish at a temperature of 194°F to 212°F (90°C to 100°C) for 60 min.

PRECAUTION: Provide adequate ventilation to dissipate the emitted vapor.

(4) Analysis of the residue shall be as follows: If the residue is less than 0.005 g, the material is acceptable without further analysis. If the residue is 0.005 g or more, the procedure shown in (a)(3) above shall be repeated and the residue analyzed in accordance with SD-129 or SD-1552. Alternately the material may be decomposed in accordance with SD-129 and analyzed in accordance with SD-516 Method B. The sulphur content shall not exceed 1% of the residue by weight.

(b) When examining austenitic stainless steel or titanium, all materials shall be analyzed individually for chlorine and fluorine content as follows.

(1) An individual sample of the penetrant materials with the exception of cleaners shall be prepared for analysis by heating 50 g of the material in a 150 mm nominal diameter glass Petri dish at a temperature of 194°F to 212°F (90°C to 100°C) for 60 min.

PRECAUTION: Provide adequate ventilation to dissipate the emitted vapor.

(2) If the residue is 0.0025 g or more, the procedure shown in (b)(1) above shall be repeated. The residue may be analyzed in accordance with SD-808 and the total shall not exceed 1% by weight. Or, alternately, the residue shall be analyzed in accordance with SE-165, Annex 2 for chlorine and SE-165, Annex 3 for fluorine, and the total chlorine plus fluorine content shall not exceed 1% by weight.

(3) An individual sample of the cleaner/remover material shall be prepared for analysis by heating 100 g of the material in a 150 mm nominal diameter glass Petri dish at a temperature of 194°F to 212°F (90°C to 100°C) for 60 min.

PRECAUTION: Provide adequate ventilation to dissipate the emitted vapor.

(4) If the residue is 0.005 g or more, the procedure shown in (b)(3) above shall be repeated. The residue may be analyzed in accordance with SD-808 and the total shall not exceed 1% by weight. Or, alternately, the residue shall be analyzed in accordance with SE-165, Annex 2 for chlorine and SE-165, Annex 3 for fluorine, and the total chlorine plus fluorine content shall not exceed 1% by weight.

(c) As an alternative to (a) and (b) above, SE-165, Annex A4 may be used for determination of anions by ion chromatography, which provides a single instrumental technique for rapid sequential measurement of common anions such as chloride, fluoride, and sulfate.

T-642 Surface Preparation

(a) In general, satisfactory results may be obtained when the surface of the part is in the as-welded, as-rolled, as-cast, or as-forged condition. Surface preparation by grinding, machining, or other methods may be necessary where surface irregularities could mask indications of unacceptable discontinuities.

(b) Prior to each liquid penetrant examination, the surface to be examined and all adjacent areas within at least 1 in. (25 mm) shall be dry and free of all dirt, grease, lint, scale, welding flux, weld spatter, paint, oil, and other extraneous matter that could obscure

surface openings or otherwise interfere with the examination.

(c) Typical cleaning agents which may be used are detergents, organic solvents, descaling solutions, and paint removers. Degreasing and ultrasonic cleaning methods may also be used.

(d) Cleaning solvents shall meet the requirements of T-641. The cleaning method employed is an important part of the examination process.

NOTE: Conditioning of surfaces prior to examination may affect the results. See SE-165, Annex A1.

T-643 Drying After Preparation

After cleaning, drying of the surfaces to be examined shall be accomplished by normal evaporation or with forced hot or cold air. A minimum period of time shall be established to ensure that the cleaning solution has evaporated prior to application of the penetrant.

T-650 PROCEDURE/TECHNIQUE

T-651 Techniques

Either a color contrast (visible) penetrant or a fluorescent penetrant shall be used with one of the following three penetrant processes:

(a) water washable

(b) post-emulsifying

(c) solvent removable

The visible and fluorescent penetrants used in combination with these three penetrant processes result in six liquid penetrant techniques.

T-652 Techniques for Standard Temperatures

As a standard technique, the temperature of the penetrant and the surface of the part to be processed shall not be below 50°F (10°C) nor above 125°F (52°C) throughout the examination period. Local heating or cooling is permitted provided the part temperature remains in the range of 50°F to 125°F (10°C to 52°C) during the examination. Where it is not practical to comply with these temperature limitations, other temperatures and times may be used, provided the procedures are qualified as specified in T-653.

T-653 Techniques for Nonstandard Temperatures

T-653.1 General. When it is not practical to conduct a liquid penetrant examination within the temperature range of 50°F to 125°F (10°C to 52°C), the examination procedure at the proposed lower or higher temperature range requires qualification. This shall require the use of a quench cracked aluminum block, which in this Article is designated as a liquid penetrant comparator block.

T-653.2 Liquid Penetrant Comparator. The liquid penetrant comparator blocks shall be made of aluminum, ASTM B 209, Type 2024, $^3/_8$ in. (10 mm) thick, and should have approximate face dimensions of 2 in. × 3 in. (52 mm × 76 mm). At the center of each face, an area approximately 1 in. (25 mm) in diameter shall be marked with a 950°F (510°C) temperature-indicating crayon or paint. The marked area shall be heated with a blowtorch, a Bunsen burner, or similar device to a temperature between 950°F (510°C) and 975°F (524°C). The specimen shall then be immediately quenched in cold water, which produces a network of fine cracks on each face.

The block shall then be dried by heating to approximately 300°F (149°C). After cooling, the block shall be cut in half. One-half of the specimen shall be designated block "A" and the other block "B" for identification in subsequent processing. Figure T-653.2 illustrates the comparator blocks "A" and "B." As an alternate to cutting the block in half to make blocks "A" and "B," separate blocks 2 in. × 3 in. (52 mm × 76 mm) can be made using the heating and quenching technique as described above. Two comparator blocks with closely matched crack patterns may be used. The blocks shall be marked "A" and "B."

T-653.3 Comparator Application

(a) If it is desired to qualify a liquid penetrant examination procedure at a temperature of less than 50°F (10°C), the proposed procedure shall be applied to block "B" after the block and all materials have been cooled and held at the proposed examination temperature until the comparison is completed. A standard procedure which has previously been demonstrated as suitable for use shall be applied to block "A" in the 50°F to 125°F (10°C to 52°C) temperature range. The indications of cracks shall be compared between blocks "A" and "B." If the indications obtained under the proposed conditions on block "B" are essentially the same as obtained on block "A" during examination at 50°F to 125°F (10°C to 52°C), the proposed procedure shall be considered qualified for use.

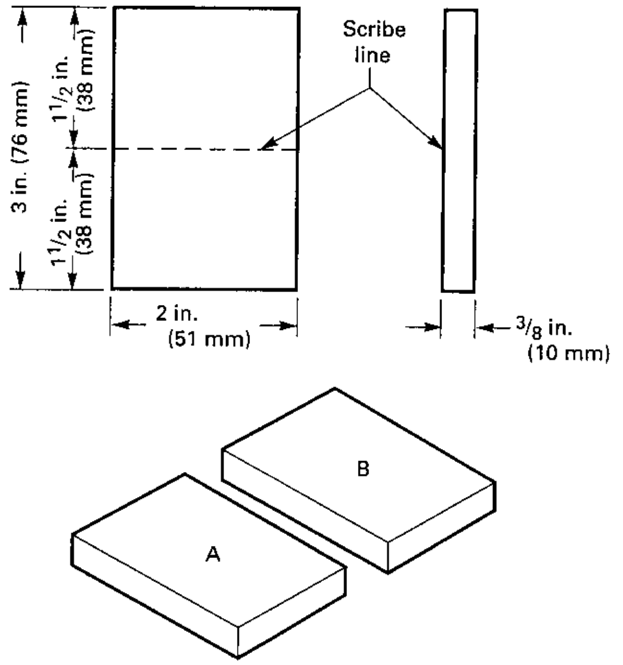


FIG. T-653.2 LIQUID PENETRANT COMPARATOR
(NOTE: Dimensions given are for guidance only and are not critical.)

(b) If the proposed temperature for the examination is above 125°F (52°C), block "B" shall be held at this temperature throughout the examination. The indications of cracks shall be compared as described in T-653.3(a) while block "B" is at the proposed temperature and block "A" is at the 50°F to 125°F (10°C to 52°C) temperature range.

(c) A procedure qualified at a temperature lower than 50°F (10°C) shall be qualified from that temperature to 50°F (10°C).

(d) To qualify a procedure for temperatures above 125°F (52°C), the upper and lower temperature limits shall be established and the procedure qualified at these temperatures.

(e) As an alternate to the requirements of T-653.3(a) and T-653.3(b) when using color contrast penetrants, it is permissible to use a single comparator block for the standard and nonstandard temperatures and to make the comparison by photography.

(1) When the single comparator block and photographic technique is used, the processing details (as applicable) described in T-653.3(a) and T-653.3(b) apply. The block shall be thoroughly cleaned between the two processing steps. Photographs shall be taken after processing at the nonstandard temperature and then after processing at the standard temperature. The indication of cracks shall be compared between the two photographs. The same criteria for qualification as T-653.3(a) shall apply.

(2) The identical photographic techniques shall be used to make the comparison photographs.

T-654 Technique Restrictions

Fluorescent penetrant examination shall not follow a color contrast penetrant examination. Intermixing of penetrant materials from different families or different manufacturers is not permitted. A retest with water washable penetrants may cause loss of marginal indications due to contamination.

T-670 EXAMINATION

T-671 Penetrant Application

The penetrant may be applied by any suitable means, such as dipping, brushing, or spraying. If the penetrant is applied by spraying using compressed-air-type apparatus, filters shall be placed on the upstream side near the air inlet to preclude contamination of the penetrant by oil, water, dirt, or sediment that may have collected in the lines.

T-672 Penetration Time

Penetration time is critical. The minimum penetration time shall be as required in Table T-672 or as qualified by demonstration for specific applications.

T-673 Excess Penetrant Removal

After the specified penetration time has elapsed, any penetrant remaining on the surface shall be removed, taking care to minimize removal of penetrant from discontinuities.

T-673.1 Water-Washable Penetrants. Excess water-washable penetrant shall be removed with a water spray. The water pressure shall not exceed 50 psi (345 kPa), and the water temperature shall not exceed 110°F (43°C).

T-673.2 Postemulsification Penetrants

(a) Lipophilic Emulsification. After the required penetrant dwell time, the excess surface penetrant shall be emulsified by immersing or flooding the part with the emulsifier. Emulsification time is dependent on the type of emulsifier and surface condition. The actual

emulsification time shall be determined experimentally. After emulsification, the mixture shall be removed by immersing in or rinsing with water. The temperature and pressure of the water shall be as recommended by the manufacturer.

(b) Hydrophilic Emulsification. After the required penetrant dwell time and prior to emulsification, the parts shall be prerinsed with water spray using the same process as for water-washable penetrants. Prerinsing time shall not exceed 1 min. After prerinsing, the excess surface penetrant shall be emulsified by immersing in or spraying with hydrophilic emulsifier. Bath concentration shall be as recommended by the manufacturer. After emulsification, the mixture shall be removed by immersing in or rinsing with water. The temperature and pressure of the water shall be as recommended by the manufacturer.

NOTE: Additional information may be obtained from SE-165.

T-673.3 Solvent Removable Penetrants. Excess solvent removable penetrants shall be removed by wiping with a cloth or absorbent paper, repeating the operation until most traces of penetrant have been removed. The remaining traces shall be removed by lightly wiping the surface with cloth or absorbent paper moistened with solvent. To minimize removal of penetrant from discontinuities, care shall be taken to avoid the use of excess solvent. **Flushing the surface with solvent, following the application of the penetrant and prior to developing, is prohibited.**

T-674 Drying After Excess Penetrant Removal

(a) For the water washable or post-emulsifying technique, the surfaces may be dried by blotting with clean materials or by using circulating air, provided the temperature of the surface is not raised above 125°F (52°C).

(b) For the solvent removable technique, the surfaces may be dried by normal evaporation, blotting, wiping, or forced air.

T-675 Developing

The developer shall be applied as soon as possible after penetrant removal; the time interval shall not exceed that established in the procedure. Insufficient coating thickness may not draw the penetrant out of discontinuities; conversely, excessive coating thickness may mask indications.

With color contrast penetrants, only a wet developer shall be used. With fluorescent penetrants, a wet or dry developer may be used.

T-675.1 Dry Developer Application. Dry developer shall be applied only to a dry surface by a soft brush, hand powder bulb, powder gun, or other means, provided the powder is dusted evenly over the entire surface being examined.

T-675.2 Wet Developer Application. Prior to applying suspension type wet developer to the surface, the developer must be thoroughly agitated to ensure adequate dispersion of suspended particles.

(a) Aqueous Developer Application. Aqueous developer may be applied to either a wet or dry surface. It shall be applied by dipping, brushing, spraying, or other means, provided a thin coating is obtained over the entire surface being examined. Drying time may be decreased by using warm air, provided the surface temperature of the part is not raised above 125°F. Blotting is not permitted.

(b) Nonaqueous Developer Application. Nonaqueous developer shall be applied only to a dry surface. It shall be applied by spraying, except where safety or restricted access preclude it. Under such conditions, developer may be applied by brushing. Drying shall be by normal evaporation.

T-675.3 Developing time for final interpretation begins immediately after the application of a dry developer or as soon as a wet developer coating is dry. The minimum developing time shall be as required by Table T-672.

T-676 Interpretation

T-676.1 Final Interpretation. Final interpretation shall be made within 7 to 60 min after the requirements of T-675.3 are satisfied. If bleed-out does not alter the examination results, longer periods are permitted. If the surface to be examined is large enough to preclude complete examination within the prescribed or established time, the examination shall be performed in increments.

T-676.2 Characterizing Indication(s). The type of discontinuities are difficult to evaluate if the penetrant diffuses excessively into the developer. If this condition occurs, close observation of the formation of indication(s) during application of the developer may assist in characterizing and determining the extent of the indication(s).

TABLE T-672 MINIMUM DWELL TIMES

Material	Form	Type of Discontinuity	Dwell Times [Note (1)] (minutes) Penetrant	Developer
Aluminum, magnesium, steel, brass and bronze, titanium and high-temperature alloys	Castings and welds	Cold shuts, porosity, lack of fusion, cracks (all forms)	5	7
	Wrought materials — extrusions, forgings, plate	Laps, cracks (all forms)	10	7
Carbide-tipped tools		Lack of fusion, porosity, cracks	5	7
Plastic	All forms	Cracks	5	7
Glass	All forms	Cracks	5	7
Ceramic	All forms	Cracks, porosity	5	7

NOTE:
(1) For temperature range from 50°F to 125°F (10°C to 52°C).

T-676.3 Color Contrast Penetrants. With a color contrast penetrant, the developer forms a reasonably uniform white coating. Surface discontinuities are indicated by bleed-out of the penetrant which is normally a deep red color that stains the developer. Indications with a light pink color may indicate excessive cleaning. Inadequate cleaning may leave an excessive background making interpretation difficult. A minimum light intensity of 50 fc (500 Lx) is required to ensure adequate sensitivity during the examination and evaluation of indications.

T-676.4 Fluorescent Penetrants. With fluorescent penetrants, the process is essentially the same as in T-676.3, with the exception that the examination is performed using an ultraviolet light, called *black light*. The examination shall be performed as follows:

(*a*) It shall be performed in a darkened area.

(*b*) The examiner shall be in the darkened area for at least 1 min prior to performing the examination to enable his eyes to adapt to dark viewing. If the examiner wears glasses or lenses, they shall not be photosensitive.

(*c*) The black light shall be allowed to warm up for a minimum of 5 min prior to use or measurement of the intensity of the ultraviolet light emitted.

(*d*) The black light intensity shall be measured with a black light meter. A minimum of 1000 $\mu W/cm^2$ on the surface of the part being examined shall be required. The black light intensity shall be measured at least once every 8 hr, and whenever the work station is changed.

T-677 Post-examination Cleaning

When post-examination cleaning is required by the procedure, it should be conducted as soon as practical using a process that does not adversely affect the part.

T-680 EVALUATION

(*a*) All indications shall be evaluated in terms of the acceptance standards of the referencing Code Section.

(*b*) Discontinuities at the surface will be indicated by bleed-out of penetrant; however, localized surface irregularities due to machining marks or other surface conditions may produce false indications.

(*c*) Broad areas of fluorescence or pigmentation which could mask indications of discontinuities are unacceptable, and such areas shall be cleaned and reexamined.

T-690 DOCUMENTATION/RECORDS

T-690.1 Documentation/records shall be in accordance with the referencing Code Section.

ARTICLE 6
MANDATORY APPENDIX

APPENDIX I — GLOSSARY OF TERMS FOR LIQUID PENETRANT EXAMINATION

I-610 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definition of terms which appear in Article 6, Liquid Penetrant Examination.

I-620 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 Section G provides the definitions of terms listed in I-630(a).

(c) For general terms, such as *Indication, Flaw, Discontinuity, Evaluation*, etc., refer to Article 1, Mandatory Appendix 1.

(d) Paragraph I-630(b) provides a list of terms and definitions, which are in addition to SE-1316 and are Code specific.

I-630 REQUIREMENTS

(a) The following SE-1316 terms are used in conjunction with this Article: black light; bleedout; blotting; clean; contaminant; contrast; developer; developer, aqueous; developer, dry; developer, nonaqueous; developing time; drying time; dwell time; emulsifier; family; fluorescence; overemulsification; penetrant; penetrant comparator; penetrant fluorescent; penetrant, water washable; post-cleaning; post emulsification; precleaning; rinse; solvent remover.

(b) The following Code terms are used in conjunction with this Article:

black light intensity — a quantitative expression of ultraviolet irradiance

color contrast penetrant — a highly penetrating liquid incorporating a nonfluorescent dye, which produces indications of such intensity that they are readily visible during examination under white light

post emulsification penetrant — a type of penetrant containing no emulsifier, but which requires a separate emulsifying step to facilitate water rinse removal of the surface penetrant

solvent removable penetrant — a type of penetrant used where the excess penetrant is removed from the surface of the part by wiping using a nonaqueous liquid

01

ARTICLE 7

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ARTICLE 7
MAGNETIC PARTICLE EXAMINATION

T-710 SCOPE

When specified by the referencing Code Section, the magnetic particle examination techniques described in this Article shall be used. In general, this Article is in conformance with SE-709, Standard Guide for Magnetic Particle Examination. This document provides details to be considered in the procedures used.

When this Article is specified by a referencing Code Section, the magnetic particle method described in this Article shall be used together with Article 1, General Requirements. Definition of terms used in this Article are in Mandatory Appendix II.

T-720 GENERAL

The magnetic particle examination method may be applied to detect cracks and other discontinuities on or near the surfaces of ferromagnetic materials. The sensitivity is greatest for surface discontinuities and diminishes rapidly with increasing depth of subsurface discontinuities below the surface. Typical types of discontinuities that can be detected by this method are cracks, laps, seams, cold shuts, and laminations.

In principle, this method involves magnetizing an area to be examined, and applying ferromagnetic particles (the examinations medium) to the surface. The particles will form patterns on the surface where cracks and other discontinuities cause distortions in the normal magnetic field. These patterns are usually characteristic of the type of discontinuity that is detected.

Whichever technique is used to produce the magnetic flux in the part, maximum sensitivity will be to linear discontinuities oriented perpendicular to the lines of flux. For optimum effectiveness in detecting all types of discontinuities, each area should be examined at least twice, with the lines of flux during one examination approximately perpendicular to the lines of flux during the other.

T-730 EQUIPMENT

A suitable and appropriate means for producing the necessary magnetic flux in the part shall be employed, using one or more of the techniques listed in T-752 and described in T-770.

T-731 Examination Medium

The finely divided ferromagnetic particles used for the examination shall meet the following requirements.

(a) Particle Types. The particles shall be treated to impart color (fluorescent pigments, nonfluorescent pigments, or both) in order to make them highly visible (contrasting) against the background of the surface being examined.

(b) Particles. Dry and wet particles, including wet particle suspension vehicles, and particle concentrations shall be in accordance with SE-709.

(c) Temperature Limitations. Particles shall be used within the temperature range limitations set by the manufacturer. Alternatively, particles may be used outside the manufacturer's recommendations providing the procedure is qualified in accordance with Article 1, T-150.

T-740 REQUIREMENTS

T-741 Surface Conditioning

T-741.1 Preparation

(a) Satisfactory results are usually obtained when the surfaces are in the as-welded, as-rolled, as-cast, or as-forged conditions. However, surface preparation by grinding or machining may be necessary where surface irregularities could mask indications due to discontinuities.

(b) Prior to magnetic particle examination, the surface to be examined and all adjacent areas within at least 1 in. (25 mm) shall be dry and free of all dirt, grease, lint, scale, welding flux and spatter, oil, or

other extraneous matter that could interfere with the examination.

(c) Cleaning may be accomplished using detergents, organic solvents, descaling solutions, paint removers, vapor degreasing, sand or grit blasting, or ultrasonic cleaning methods.

(d) If coatings are left on the part in the area being examined, it must be demonstrated that indications can be detected through the existing maximum coating thickness applied. When AC yoke technique is used, the demonstration must be in accordance with Mandatory Appendix I of this Article.

T-741.2 Surface Contrast Enhancement. When coatings are applied temporarily to uncoated surfaces only in amounts sufficient to enhance particle contrast, it must be demonstrated that indications can be detected through the enhancement coating.

NOTE: Refer to T-150(a) for guidance for the demonstration required in T-741.1(d) and T-741.2.

01 T-750 PROCEDURE REQUIREMENTS

Magnetic particle examination shall be performed in accordance with a written procedure.

Each procedure shall include at least the following information, as applicable:

(a) the materials, shapes, or sizes to be examined, and the extent of the examination;

(b) magnetization techniques to be used;

(c) equipment to be used for magnetization;

(d) surface preparation (finishing and cleaning);

(e) type of ferromagnetic particles to be used: manufacturer, color, wet or dry, etc.;

(f) maximum allowable temperature for ferromagnetic particles to be used: per manufacturer recommendation or by qualification;

(g) magnetization currents (type and amperage);

(h) demagnetization;

(i) post-examination cleaning.

T-751 Method of Examination

Examination shall be done by the continuous method; that is, the magnetizing current remains on while the examination medium is being applied and while excess of the examination medium is being removed.

T-752 Techniques and Materials

The ferromagnetic particles used as an examination medium shall be either wet or dry, and may be either fluorescent or nonfluorescent.

One or more of the following five magnetization techniques shall be used:

(a) prod technique;

(b) longitudinal magnetization technique;

(c) circular magnetization technique;

(d) yoke technique;

(e) multidirectional magnetization technique.

T-753 Magnetizing Field Adequacy and Direction

T-753.1 Magnetic Field Adequacy. The applied magnetic field shall have sufficient strength to produce satisfactory indications, but it shall not be so strong that it causes the masking of relevant indications by nonrelevant accumulations of magnetic particles. Factors that influence the required field strength include the size, shape, and material permeability of the part; the technique of magnetization; coatings; the method of particle application; and the type and location of discontinuities to be detected. When it is necessary to verify the adequacy of magnetic field strength, it shall be verified by using one or more of the following three methods.

T-753.1.1 Pie-Shaped Magnetic Particle Field Indicator. The indicator, shown in Fig. T-753.1.1, shall be positioned on the surface to be examined, such that the copper-plated side is away from the inspected surface. A suitable field strength is indicated when a clearly defined line (or lines) of magnetic particles form(s) across the copper face of the indicator when the magnetic particles are applied simultaneously with the magnetizing force. When a clearly defined line of particles is not formed, the magnetizing technique shall be changed as needed. Pie-type indicators are best used with dry particle procedures.

T-753.1.2 Artificial Flaw Shims. The shim, shown in Fig. T-753.1.2, shall be attached to the surface to be examined, such that the artificial flaw side of the shim is toward the inspected surface. A suitable field strength is indicated when a clearly defined line (or lines) of magnetic particles, representing the 30% depth flaw, appear(s) on the shim face when magnetic particles are applied simultaneously with the magnetizing force. When a clearly defined line of particles is not formed, the magnetizing technique shall be changed as needed.

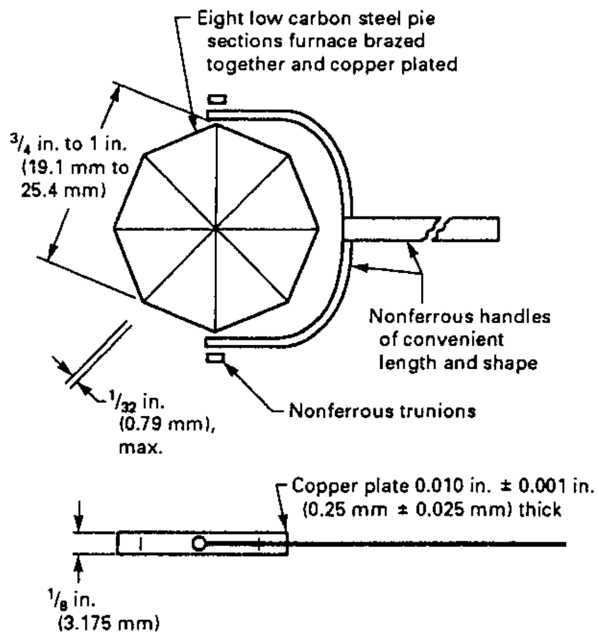
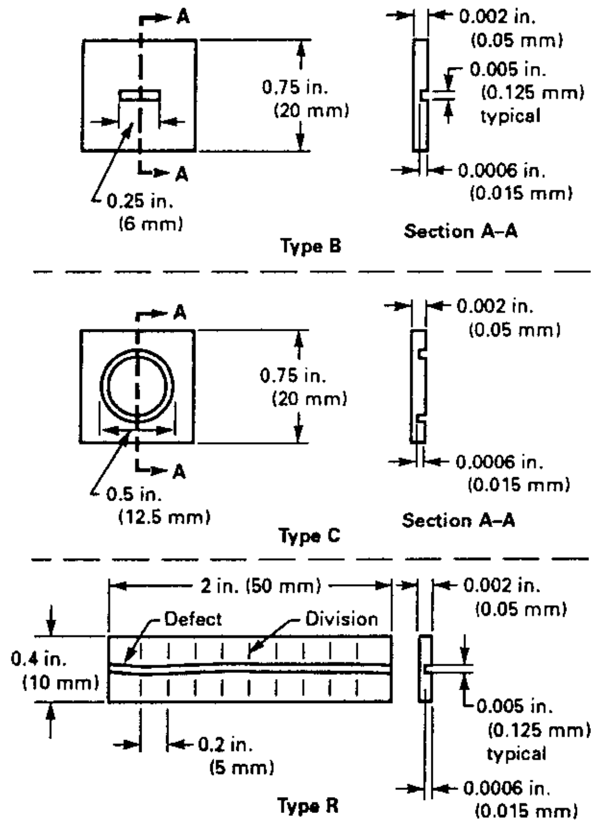


FIG. T-753.1.1 PIE-SHAPED MAGNETIC PARTICLE FIELD INDICATOR



GENERAL NOTE:
Above are examples of artificial flaw shims used in magnetic particle inspection system verification (not drawn to scale). The shims are made of low carbon steel (1005 steel foil). The artificial flaw is etched or machined on one side of the foil to a depth of 30% of the foil thickness.

FIG. T-753.1.2 ARTIFICIAL FLAW SHIMS

Shim-type indicators are best used with wet particle procedures.

T-753.1.3 Hall-Effect Tangential-Field Probe. A gaussmeter and Hall-Effect tangential-field probe shall be used for measuring the peak value of a tangential field. The probe shall be positioned on the surface to be examined, such that the maximum field strength is determined. A suitable field strength is indicated when the measured field is within the range of 30 G to 60 G (2.4 kAm^{-1} to 4.8 kAm^{-1}) while the magnetizing force is being applied. See Article 7, Nonmandatory Appendix A.

T-753.2 Magnetic Field Direction. The direction of magnetization shall be determined by particle indications obtained using an indicator or shims as shown in Fig. T-753.1.1 or Fig. T-753.1.2. When a clearly defined line of particles is not formed in the desired direction, the magnetizing technique shall be changed as needed.

T-753.2.1 For multidirectional magnetization techniques, the orientation of the lines of flux shall be in at least two nearly perpendicular directions. When clearly defined lines of particles are not formed in at least two nearly perpendicular directions, the magnetizing technique shall be changed as needed.

T-753.3 Determination of the adequacy and direction of magnetizing fields using magnetic field indicators or artificial flaws are only permitted when specifically referenced by the magnetizing technique in T-774.2(c), T-774.2(d), T-775.1(b)(3), T-775.2(a), T-775.2(b), and T-777.2.

T-754 Rectified Current

(a) Whenever direct current is required rectified current may be used. The rectified current for magnetization shall be either three-phase (full-wave rectified) current, or single phase (half-wave rectified) current.

(b) The amperage required with three-phase, full-wave rectified current shall be verified by measuring the average current.

(c) The amperage required with single-phase (half-wave rectified) current shall be verified by measuring the average current output during the conducting half cycle only.

(d) When measuring half-wave rectified current with a direct current test meter, readings shall be multiplied by two.

T-755 Demagnetization

When residual magnetism in the part could interfere with subsequent processing or usage, the part shall be demagnetized any time after completion of the examination.

T-756 Post-examination Cleaning

When postexamination cleaning is required by the procedure, it should be conducted as soon as practical using a process that does not adversely affect the part.

T-760 CALIBRATION OF EQUIPMENT

T-761 Frequency of Calibration

(a) Frequency. Each piece of magnetizing equipment with an ammeter shall be calibrated at least once a year, or whenever the equipment has been subjected to major electric repair, periodic overhaul, or damage. If equipment has not been in use for a year or more, calibration shall be done prior to first use.

(b) Procedure. The accuracy of the unit's meter shall be verified annually by equipment traceable to a national standard. Comparative readings shall be taken for at least three different current output levels encompassing the usable range.

(c) Tolerance. The unit's meter reading shall not deviate by more than ±10% of full scale, relative to the actual current value as shown by the test meter.

T-762 Lifting Power of Yokes

(a) Prior to use, the magnetizing power of electromagnetic yokes shall have been checked within the past year. The magnetizing power of permanent magnetic yokes shall be checked daily prior to use. The magnetizing power of all yokes shall be checked whenever the yoke has been damaged or repaired.

(b) Each alternating current electromagnetic yoke shall have a lifting power of at least 10 lb (4.5 kg) at the maximum pole spacing that will be used.

(c) Each direct current or permanent magnetic yoke shall have a lifting power of at least 40 lb (18.1 kg) at the maximum pole spacing that will be used.

(d) Each weight shall be weighed with a scale from a reputable manufacturer and stenciled with the applicable nominal weight prior to first use. A weight need only be verified again if damaged in a manner that could have caused potential loss of material.

T-763 Gaussmeters

Hall-Effect probe gaussmeters used to verify magnetizing field strength in accordance with T-753 shall be calibrated at least once a year or whenever the equipment has been subjected to a major repair, periodic overhaul, or damage. If equipment has not been in use for a year or more, calibration shall be done prior to first use.

T-770 EXAMINATION

T-771 Direction of Magnetization

At least two separate examinations shall be performed on each area. During the second examination, the lines of magnetic flux shall be approximately perpendicular to those used during the first examination. A different technique for magnetization may be used for the second examination.

T-772 Examination Coverage

All examinations shall be conducted with sufficient field overlap to ensure 100% coverage at the required sensitivity (T-753).

T-773 Prod Technique

T-773.1 Magnetizing Procedure. For the prod technique, magnetization is accomplished by portable prod type electrical contacts pressed against the surface in the area to be examined. To avoid arcing, a remote control switch, which may be built into the prod handles, shall be provided to permit the current to be turned on after the prods have been properly positioned.

T-773.2 Magnetizing Current. Direct or rectified magnetizing current shall be used. The current shall be 100 (minimum) amp/in. (3.9 amp/mm) to 125 (maximum) amp/in. (4.9 amp/mm) of prod spacing for sections $^3/_4$ in. (19 mm) thick or greater. For sections

less than $\frac{3}{4}$ in. (19 mm) thick, the current shall be 90 amp/in. (3.5 amp/mm) to 110 amp/in. (4.3 amp/mm) of prod spacing.

T-773.3 Prod Spacing. Prod spacing shall not exceed 8 in. (203 mm). Shorter spacing may be used to accommodate the geometric limitations of the area being examined or to increase the sensitivity, but prod spacings of less than 3 in. (76 mm) are usually not practical due to banding of the particles around the prods. The prod tips shall be kept clean and dressed. If the open circuit voltage of the magnetizing current source is greater than 25 V, lead, steel, or aluminum (rather than copper) tipped prods are recommended to avoid copper deposits on the part being examined.

T-774 Longitudinal Magnetization Technique

T-774.1 Magnetizing Procedure. For this technique, magnetization is accomplished by passing current through a multi-turn fixed coil (or cables) that is wrapped around the part or section of the part to be examined. This produces a *longitudinal* magnetic field parallel to the axis of the coil.

If a fixed, prewound coil is used, the part shall be placed near the side of the coil during inspection. This is of special importance when the coil opening is more than 10 times the cross-sectional area of the part.

T-774.2 Magnetic Field Strength. Direct or rectified current shall be used to magnetize parts examined by this technique. The required field strength shall be calculated based on the length L and the diameter D of the part in accordance with (a), (b), or as established in (c), below. Long parts shall be examined in sections not to exceed 18 in. (457 mm), and 18 in. (457 mm) shall be used for the part L in calculating the required field strength. For noncylindrical parts, D shall be the maximum cross-sectional diagonal.

(a) Parts With L/D Ratios Equal to or Greater Than 4. The magnetizing current shall be within ±10% of the ampere-turns' value determined as follows:

$$\text{Ampere-turns} = \frac{35{,}000}{(L/D) + 2}$$

For example, a part 10 in. long × 2 in. diameter has an L/D ratio of 5. Therefore,

$$\frac{35{,}000}{(5 + 2)} = 5000 \text{ ampere-turns}$$

(b) Parts With L/D Ratios Less Than 4 but Not Less Than 2. The magnetizing ampere-turns shall be within ±10% of the ampere-turns' value determined as follows:

$$\text{Ampere-turns} = \frac{45{,}000}{L/D}$$

(c) If the area to be magnetized extends beyond 6 in. on either side of the coils, field adequacy shall be demonstrated using the magnetic field indicator per T-753.

(d) For large parts due to size and shape, the magnetizing current shall be 1200 ampere-turns to 4500 ampere-turns. The field adequacy shall be demonstrated using artificial flaw shims or a pie-shaped magnetic field indicator in accordance with T-753. A Hall-Effect probe gaussmeter shall not be used with encircling coil magnetization techniques.

T-774.3 Magnetizing Current. The current required to obtain the necessary magnetizing field strength shall be determined by dividing the ampere-turns obtained in steps (a) or (b) above by the number of turns in the coil as follows:

$$\text{Amperes (meter reading)} = \frac{\text{ampere-turns}}{\text{turns}}$$

For example, if a 5-turn coil is used and the ampere-turns required are 5000, use

$$\frac{5000}{5} = 1000 \text{ amperes } (\pm 10\%)$$

T-775 Circular Magnetization Technique

T-775.1 Direct Contact Technique

(a) Magnetizing Procedure. For this technique, magnetization is accomplished by passing current through the part to be examined. This produces a *circular* magnetic field that is approximately perpendicular to the direction of current flow in the part.

(b) Magnetizing Current. Direct or rectified (half-wave rectified or full-wave rectified) magnetizing current shall be used.

(1) The current shall be 300 amp/in. (12A/mm) to 800 amp/in. (31A/mm) of outer diameter.

(2) Parts with geometric shapes other than round with the greatest cross-sectional diagonal in a plane at right angles to the current flow shall determine the inches to be used in (b)(1) above.

(3) If the current levels required for (b)(1) cannot be obtained, the maximum current obtainable shall be

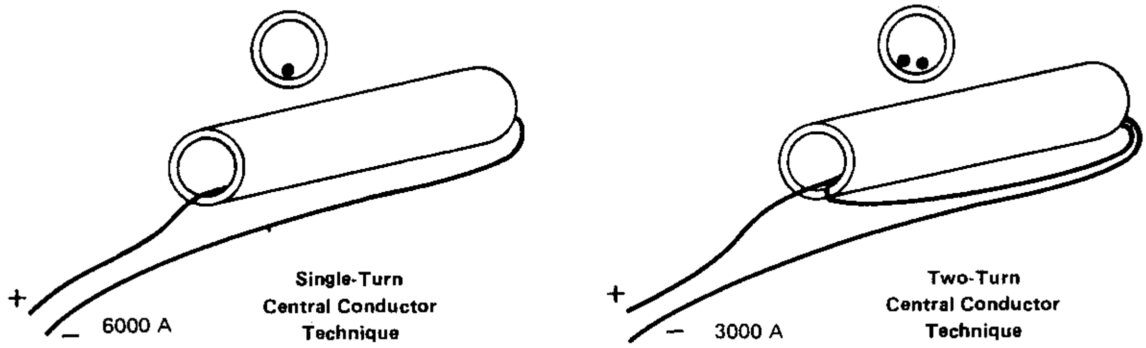


FIG. T-775.2 SINGLE-TURN AND TWO-TURN CENTRAL CONDUCTOR TECHNIQUE

used and the field adequacy shall be demonstrated in accordance with T-753.

T-775.2 Central Conductor Technique

(a) Magnetizing Procedure. For this technique, a central conductor is used to examine the internal surfaces of cylindrically or ring-shaped parts. The central conductor technique may also be used for examining the outside surfaces of these shapes. Where large diameter cylinders are to be examined, the conductor shall be positioned close to the internal surface of the cylinder. When the conductor is not centered, the circumference of the cylinder shall be examined in increments. Field strength measurements in accordance with T-753 shall be used to determine the extent of the arc that may be examined for each conductor position. Bars or cables, passed through the bore of a cylinder, may be used to induce circular magnetization.

(b) Magnetizing Current. The field strength required shall be equal to that determined in T-775.1(b) for a single-turn central conductor. The magnetic field will increase in proportion to the number of times the central conductor cable passes through a hollow part. For example, if 6000 amperes are required to examine a part using a single central conductor, then 3000 amperes are required when 2 turns of the through-cable are used, and 1200 amperes are required if 5 turns are used (see Fig. T-775.2). When the central conductor technique is used, magnetic field adequacy shall be verified using a magnetic particle field indicator in accordance with T-753.

T-776 Yoke Technique

T-776.1 Application. This method shall only be applied to detect discontinuities that are open to the surface of the part.

T-776.2 Magnetizing Procedure. For this technique alternating or direct current electromagnetic yokes, or permanent magnet yokes, shall be used.

NOTE: Except for materials $\frac{1}{4}$ in. (6 mm) or less in thickness, alternating current yokes are superior to direct or permanent magnet yokes of equal lifting power for the detection of surface discontinuities.

T-777 Multidirectional Magnetization Technique

T-777.1 Magnetizing Procedure. For this technique magnetization is accomplished by high amperage power packs operating as many as three circuits that are energized one at a time in rapid succession. The effect of these rapidly alternating magnetizing currents is to produce an overall magnetization of the part in multiple directions. Circular or longitudinal magnetic fields may be generated in any combination using the various techniques described in T-774 and T-775.

T-777.2 Magnetic Field Strength. Only three phase, full-wave rectified current shall be used to magnetize the part. The initial magnetizing current requirements for each circuit shall be established using the previously described guidelines (see T-774 and T-775). The adequacy of the magnetic field shall be demonstrated using artificial flaw shims or a pie-shaped magnetic particle field indicator in accordance with T-753. A Hall-Effect probe gaussmeter shall not be used to measure field adequacy for the multidirectional magnetization technique. An adequate field shall be obtained in at least two nearly perpendicular directions, and the field intensities shall be balanced so that a strong field in one direction does not overwhelm the field in the other direction. For areas where adequate field strengths cannot be demonstrated, additional magnetic particle

techniques shall be used to obtain the required two-directional coverage.

T-778 Interpretation

01 **T-778.1 Nonfluorescent Particles.** With nonfluorescent particles, the examination is performed using visible light. A minimum light intensity of 100 fc (1000 Lx) is required to ensure adequate sensitivity during the examination and evaluation of indications. The light source, technique used, and light level verification is required to be demonstrated one time, documented, and maintained on file.

T-778.2 Fluorescent Particles. With fluorescent particles the examination is performed using an ultraviolet light, called *black light.* The examination shall be performed as follows:

(a) It shall be performed in a darkened area.

(b) The examiner shall be in the darkened area for at least 5 min prior to performing the examination to enable his eyes to adapt to dark viewing. If the examiner wears glasses or lenses, they shall not be photosensitive.

(c) The black light shall be allowed to warm up for a minimum of 5 min prior to use or measurement of the intensity of the ultraviolet light emitted.

(d) The black light intensity shall be measured with a black light meter. A minimum of 1000 $\mu W/cm^2$ on the surface of the part being examined shall be required. The black light intensity shall be measured at least once every 8 hr, and whenever the work station is changed.

T-780 EVALUATION

(a) All indications shall be evaluated in terms of the acceptance standards of the referencing Code Section.

(b) Discontinuities on or near the surface are indicated by retention of the examination medium. However, localized surface irregularities due to machining marks or other surface conditions may produce false indications.

(c) Broad areas of particle accumulation, which might mask indications from discontinuities, are prohibited, and such areas shall be cleaned and re-examined.

T-790 RECORDS

T-791 Multidirectional Magnetization Technique Sketch

A technique sketch shall be prepared for each different geometry examined, showing the part geometry, cable arrangement and connections, magnetizing current for each circuit, and the areas of examination where adequate field strengths are obtained. Parts with repetitive geometries, but different dimensions, may be examined using a single sketch provided that the magnetic field strength is adequate when demonstrated in accordance with T-777.2.

ARTICLE 7
MANDATORY APPENDICES

APPENDIX I — MAGNETIC PARTICLE EXAMINATION ON COATED FERRITIC MATERIALS USING THE AC YOKE TECHNIQUE

I-710 SCOPE

This Appendix provides the Magnetic Particle examination methodology and equipment requirements applicable for performing Magnetic Particle examination on coated ferritic materials.

I-720 GENERAL

I-721 Personnel Qualification

Personnel qualification requirements shall be in accordance with the referencing Code Section.

I-730 EQUIPMENT

I-730.1 The magnetizing equipment shall be in accordance with Article 7.

I-730.2 When the dry powder technique is used, a powder blower shall be utilized for powder application. Hand squeezed particle applicators shall not be used when the dry powder technique is utilized.

I-730.3 Magnetic particles shall contrast with the component background.

I-730.4 Nonconductive materials such as plastic shim stock may be used to simulate nonconductive coatings for procedure and personnel qualification.

I-750 PROCEDURE/TECHNIQUE

I-750.1 Procedure

Magnetic particle examination shall be performed in accordance with a written procedure. The procedure shall include the following:

(a) identification of surface configurations to be examined, including coating materials, maximum qualified coating thickness, and product forms (e.g., base material or welded surface)

(b) surface condition requirements and preparation methods

(c) manufacturer and model of AC yoke

(d) manufacturer and type of magnetic particles

(e) minimum and maximum yoke leg separation

(f) method of measuring coating thickness

(g) identification of the steps in performing the examination

(h) minimum lighting and AC yoke lifting power requirements (as measured in accordance with Procedure Qualification I-752)

(i) methods of identifying flaw indications and discriminating between flaw indications and nonrelevant indications (e.g., magnetic writing or particle held by surface irregularities)

(j) instructions for identification and confirmation of suspected flaw indications

(k) recording criteria

(l) personnel qualification requirements

(m) reference to the procedure qualification records

(n) method of verifying that the yoke lifting power and the illumination source used in the production examination are at least as great as specified.

I-751 Coating Thickness Measurement

The procedure demonstration and performance of examinations shall be preceded by measurement of the coating thickness in the areas to be examined. If the coating is nonconductive, an eddy current technique may be used to measure the coating thickness. If the coating is conductive, a magnetic coating thickness technique shall be used in accordance with ASTM D 1186. Coating measurement equipment shall be used in accordance with the equipment manufacturer's instructions. Coating thickness measurements shall be taken at the intersections of a 2 in. (51 mm) maximum

grid pattern over the area of examination and at least one-half the maximum yoke leg separation beyond the examination area. The thickness shall be the mean of three separate readings within $\frac{1}{4}$ in. (6 mm) of each intersection.

I-752 Procedure Demonstration

The procedure shall be demonstrated to the satisfaction of the Inspector in accordance with the requirements of the referencing Code Section.

I-753 Procedure Qualification

(a) A qualification specimen is required. The specimen shall be of similar geometry or weld profile and contain at least one surface crack no longer than the maximum flaw size allowed in the applicable acceptance criteria. The material used for the specimen shall be the same specification and heat treatment as the coated ferromagnetic material to be examined. As an alternative to the material requirement, other materials and heat treatments may be qualified provided:

(1) The measured yoke maximum lifting force on the material to be examined is equal to or greater than the maximum lifting force on the qualification specimen material. Both values shall be determined with the same or comparable equipment and shall be documented as required in paragraph (c).

(2) All the requirements of paragraphs *(b)* through *(g)* are met for the alternate material.

(b) Examine the uncoated specimen in the most unfavorable orientation expected during the performance of the production examination.

(c) Document the measured yoke maximum lifting power, illumination levels, and the results.

(d) Measure the maximum coating thickness on the item to be examined in accordance with the requirements of I-751.

(e) Coat the specimen with the same type of coating, conductive or nonconductive, to the maximum thickness measured on the production item to be examined. Alternately, nonconductive shim stock may be used to simulate nonconductive coatings.

(f) Examine the coated specimen in the most unfavorable orientation expected during the performance of the production examination. Document the measured yoke maximum lifting power, illumination level, and examination results.

(g) Compare the length of the indication resulting from the longest flaw no longer than the maximum flaw size allowed by the applicable acceptance criteria, before and after coating. The coating thickness is qualified when the length of the indication on the coated surface is at least 50% of the length of the corresponding indication prior to coating.

(h) Requalification of the procedure is required for a decrease in either the AC yoke lifting power or the illumination level, or for an increase in the coating thickness.

I-770 EXAMINATION

(a) Surfaces to be examined, and all adjacent areas within at least 1 in. (25 mm), shall be free of all dirt, grease, lint, scale, welding flux and spatter, oil, and loose, blistered, flaking, or peeling coating.

(b) Examine the coated item in accordance with the qualified procedure.

I-780 EVALUATION

If an indication greater than 50% of the maximum allowable flaw size is detected, the coating in the area of the indication shall be removed and the examination repeated.

I-790 DOCUMENTATION/RECORDS

Procedure qualification documentation shall include the following:

(a) identification of the procedure

(b) identification of the personnel performing and witnessing the qualification

(c) description and drawings or sketches of the qualification specimen, including coating thickness measurements and flaw dimensions

(d) equipment and materials used

(e) illumination level and yoke lifting power

(f) qualification results, including maximum coating thickness and flaws detected.

APPENDIX II — GLOSSARY OF TERMS FOR MAGNETIC PARTICLE EXAMINATION

II-710 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definition of terms

which appear in Article 7, Magnetic Particle Examination.

II-720 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 Section 10 provides the definitions of terms listed in II-730(a).

(c) For general terms, such as *Indication, Flaw, Discontinuity, Evaluation*, etc., refer to Article 1, Mandatory Appendix I.

(d) Paragraph II-730(b) provides a list of terms and definitions, which are in addition to SE-1316 and are Code specific.

II-730 REQUIREMENTS

(a) The following SE-1316 terms are used in conjunction with this Article: ampere turns, black light, central conductor, circular magnetization, demagnetization, dry powder, full-wave direct current, half-wave current, longitudinal magnetization, magnetic field, magnetic field strength, magnetic particle examination, magnetic particle field indicator, magnetic particles, multidirectional magnetization, permanent magnet, prods, sensitivity, suspension, yoke.

(b) The following Code terms are used in conjunction with this Article:

black light intensity — a quantitative expression of ultraviolet irradiance

magnetic flux — the concept that the magnetic field is flowing along the lines of force suggests that these lines are therefore "flux" lines, and they are called magnetic flux. The strength of the field is defined by the number of flux lines crossing a unit area taken at right angles to the direction of the lines.

rectified magnetic current — by means of a device called a rectifier, which permits current to flow in one direction only, alternating current can be converted to unidirectional current. This differs from direct current in that the current value varies from a steady level. This variation may be extreme, as in the case of the half-wave rectified single phase AC, or slight, as in the case of three-phase rectified AC.

half-wave rectified current AC — when a single-phase alternating current is rectified in the simplest manner, the reverse of the cycle is blocked out entirely. The result is a pulsating unidirectional current with intervals when no current at all is flowing. This is often referred to as "half-wave" or pulsating direct current.

full-wave rectified current — when the reverse half of the cycle is turned around to flow in the same direction as the forward half. The result is full-wave rectified current. Three-phase alternating current when full-wave rectified is unidirectional with very little pulsation; only a ripple of varying voltage distinguishes it from straight DC single-phase, full rectified current is usually not employed for magnetic particle examination.

01

ARTICLE 7 — APPENDIX III
MAGNETIC FLUX LEAKAGE (MFL) EXAMINATION

III-710 SCOPE

This Appendix describes the Magnetic Flux Leakage (MFL) examination method equipment requirements applicable for performing MFL examinations on coated and uncoated ferromagnetic materials from one surface. MFL is generally used as a post construction examination method to evaluate the condition of plate materials, such as storage tank floors and piping for corrosion or other forms of degradation. Other imperfections that may be detected are cracks, seams, dents, laps, and nonmetallic inclusions, etc.

III-711 References

When the Magnetic Flux Leakage method of Article 7, Appendix III is specified by a referencing Code Section, the MFL method shall be used together with Article 1, General Requirements.

III-720 GENERAL

III-721 Personnel Qualification Requirements

The user of this Appendix shall be responsible for documented training, qualification, and certification of personnel performing MFL examination. Personnel performing supplemental examinations, such as ultrasonic (UT) examinations, shall be qualified in accordance with the referencing Code Section.

III-722 Equipment Qualification Requirements

The equipment operation shall be demonstrated by successfully completing the unit verification and function tests outlined as follows:

(a) Reference Plate. All MFL examinations shall have a reference plate to ensure the equipment is performing in accordance with the manufacturer's specifications, prior to use. The reference plate shall consist of a plate that is made from a material of the same nomial thickness, product form, and composition as the component to be examined. The plate shall have notches, drilled holes, or other discontinuities machined into the bottom side of the plate, as shown in Figure III-722. The depths and widths of artificial discontinuities should be similar to the sizes and physical characteristics of discontinuities to be detected. If coatings or temporary coverings will be present during the examination, the reference plate shall be coated or covered with the coatings or covers representative of the maximum thickness that will be encountered during the examination.

(b) System Verification and Function Checks. The manufacturer's verification procedure shall be conducted initially to ensure that the system is functioning as designed. The functional check shall be made by scanning the reference plate over the range of scanning speeds to be utilized during the examination. Equipment settings shall be documented.

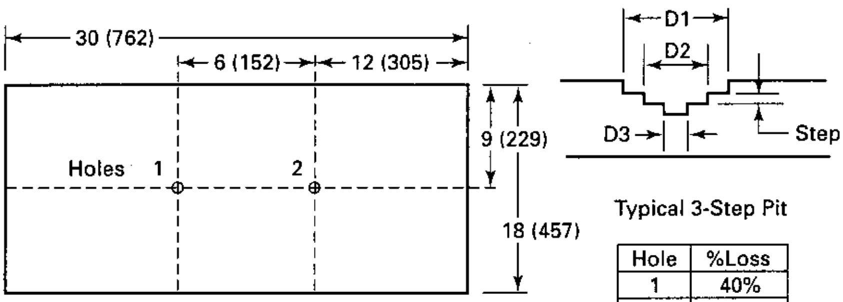
(c) Performance Confirmation. A functional check shall be conducted at the beginning and end of each examination, every eight hours, or when equipment has malfunctioned and been repaired. If it is determined that the equipment is not functioning properly, needed adjustments shall be made and all areas examined since the last performance check shall be re-inspected.

III-723 Written Procedure Requirements

III-723.1 Requirements. Magnetic Flux Leakage examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table III-723. The written procedure shall establish a single value, or range of values, for each requirement.

III-723.1.1 The procedure shall address, as a minimum, the identification of imperfections, reference materials used to set up equipment, location and mapping of imperfections, and the extent of coverage. The procedure shall address the field strength of the magnets, the functioning of the sensors and the operation of the signal-processing unit. Other examination methods that will be used to supplement the MFL examination shall be identified in the procedure.

Plate Thickness	Hole Number	Number of Steps	Step Size	Diameter D1	Diameter D2	Diameter D3	Diameter D4	Diameter D5
.25 (6)	1	3	.032 (0.8)	.47 (12)	.32 (8)	.12 (3)		
	2	4	.032 (0.8)	.62 (16)	.47 (12)	.32 (8)	.12 (3)	
.31 (8)	1	4	.032 (0.8)	.62 (16)	.47 (12)	.32 (8)	.16 (4)	
	2	5	.032 (0.8)	.78 (20)	.62 (16)	.47 (12)	.32 (8)	.16 (4)
.38 (10)	1	4	.039 (1)	.78 (20)	.59 (15)	.39 (10)	.2 (5)	
	2	5	.039 (1)	.96 (24.5)	.78 (20)	.59 (15)	.39 (10)	.2 (5)



Hole	%Loss
1	40%
2	50%

GENERAL NOTE: Dimensions of references are in in. (mm).

FIG. III-722 MFL REFERENCE PLATE DIMENSIONS

III-723.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Table III-723, identified as an essential variable from the specified value, or range of values, shall require requalification of the written procedure. A change of a requirement identified as a nonessential variable from the specified value or range of values, does not require requalification of the written procedure. All changes of essential or nonessential variables from the value or range of values specified by the written procedure shall require revision of or an addendum to the written procedure.

III-730 EQUIPMENT

The equipment shall consist of magnets, sensor or sensor array, and related electronic circuitry. A reference indicator, such as a ruled scale or linear array of illuminated light emitting diodes, should be used to provide a means for identifying the approximate lateral position of indications. The equipment may be designed for manual scanning or may be motor driven. Software may be incorporated to assist in detection and characterization of discontinuities.

TABLE III-723
REQUIREMENTS OF AN MFL EXAMINATION PROCEDURE

Requirement	Essential Variable	Non-Essential Variable
Equipment Manufacturer/Model	X	
Sensor Type; Manufacturer and Model	X	
Scanning Speed/Speed Range	X	
Scanning Technique (Remote Control/Manual)		X
Overlap	X	
Lift-off	X	
Material examined	X	
Material Thickness Range and Dimensions	X	
Reference Plate and Calibration Materials	X	
Scanning Equipment/Fixtures		X
Data Recording Equipment		X
Software	X	
Evaluation of Indications	X	
Surface Conditioning	X	
Coating/Sheet	X	

III-740 REQUIREMENTS

(a) The surface shall be cleaned of all loose scale and debris that could interfere with the examination and movement of the scanner. The surface should be sufficiently flat to minimize excessive changes in lift-off and vibration. Alternate techniques will be required to handle variables exceeding those specified in the procedure.

(b) Cleaning may be accomplished using high-pressure water blast or by sandblasting. If the material is coated and the coating is not removed, it shall be demonstrated that the MFL equipment can detect the specified imperfections through the maximum thickness of the coating.

(c) If a temporary sheet or coating is applied between the scanner and plate to provide a smooth surface, for example, on a heavily pitted surface, it must be demonstrated that the equipment can find the specified imperfections through the maximum thickness of the temporary sheet or coating.

III-760 CALIBRATION

The MFL equipment shall be recalibrated annually and whenever the equipment is subjected to major damage following required repairs. If equipment has not been in use for a year or more, calibration shall be done prior to first use.

III-770 EXAMINATION

(a) Areas to be examined shall be scanned in accordance with the written procedure. Each pass of the sensing unit shall be overlapped in accordance with the written procedure.

(b) The unit shall be scanned manually or by a motor driven system. Other examination methods may be used to provide coverage in areas not accessible to MFL examinations, in accordance with the written procedure. Typical examples of inaccessible areas in storage tanks are lap welds and corner welds adjacent to the shell or other obstructions, such as roof columns and sumps.

(c) Imperfections detected with MFL during this procedure shall be confirmed by supplemental examination. Supplemental examinations shall be performed in accordance with written procedures.

(d) Where detection of linear imperfections is required, an additional scan shall be performed in a direction approximately perpendicular to the initial scanning direction.

III-780 EVALUATION

All indications shall be evaluated in accordance with the referencing Code Section.

III-790 DOCUMENTATION

A report of the examination shall contain the following information:

(a) plate material specification, nominal wall thickness, pipe diameter, as applicable;

(b) description, such as drawing/sketches, documenting areas examined, and/or areas inaccessible;

(c) identification of the procedure used for the examination;

(d) system detection sensitivity (minimum size of imperfections detectable);

(e) location, depth, and type of all imperfections that meet or exceed the reporting criteria;

(f) examination personnel identity, and, when required by referencing Code Section, qualification level;

(g) model and serial number of equipment utilized for the examination, including supplemental equipment;

(h) date and time of examination;

(i) date and time of performance verification checks;

(j) supplemental methods utilized and referenced to associated reports.

ARTICLE 7
NONMANDATORY APPENDIX

APPENDIX A — MEASUREMENT OF TANGENTIAL FIELD STRENGTH WITH GAUSSMETERS

A-710 SCOPE

This Nonmandatory Appendix is used for the purpose of establishing procedures and equipment specifications for measuring the tangential applied magnetic field strength.

A-720 GENERAL REQUIREMENTS

Personnel qualification requirements shall be in accordance with Article 1.

Gaussmeters and related equipment shall be calibrated in accordance with T-763 of Article 7.

Definitions: standard terminology for magnetic particle examinations is presented in SE-1316.

A-730 EQUIPMENT

Gaussmeter having the capability of being set to read peak values of field intensity. The frequency response of the gaussmeter shall be at least 0 Hz to 300 Hz.

The Hall-Effect tangential field probe should be no larger than 0.2 in. (5 mm) by 0.2 in. (5 mm) and should have a maximum center location 0.2 in. (5 mm) from the part surface. Probe leads shall be shielded or twisted to prevent reading errors due to voltage induced during the large field changes encountered during magnetic particle examinations.

A-750 PROCEDURE

Care must be exercised when measuring the tangential applied field strengths specified in T-753.1.3. The plane of the probe must be perpendicular to the surface of the part at the location of measurement to within 5 deg. This may be difficult to accomplish by hand orientation. A jig or fixture may be used to ensure this orientation is achieved and maintained.

The direction and magnitude of the tangential field on the part surface can be determined by placing the Hall-Effect tangential field probe on the part surface in the area of interest. The direction of the field can be determined during the application of the magnetizing field by rotating the tangential field probe while in contact with the part until the highest field reading is obtained on the Gaussmeter. The orientation of the probe, when the highest field is obtained, will indicate the field direction at that point. Gaussmeters cannot be used to determine the adequacy of magnetizing fields for multidirectional and coil magnetization techniques.

Once adequate field strength has been demonstrated with artificial flaw shims, Gaussmeter readings may be used at the location of shim attachment on identical parts or similar configurations to verify field intensity and direction.

A-790 DOCUMENTATION/RECORDS

Documentation should include the following:

(a) equipment model and probe description;

(b) sketch or drawing showing where measurements are made; and

(c) field intensity and direction of measurement.

ARTICLE 8

Mandatory Appendices

Figures

Table

ARTICLE 8
EDDY CURRENT EXAMINATION OF TUBULAR PRODUCTS

01 T-810 SCOPE

(a) This Article describes the method to be used when performing eddy current examination of seamless copper, copper alloy, and other nonferromagnetic tubular products. The method conforms substantially with the following Standard listed in Article 26 and reproduced in Subsection B:

SE-243 Electromagnetic (Eddy Current) Testing of Seamless Copper and Copper-Alloy Heat Exchanger and Condenser Tubes.

(b) The requirements of Article 1, General Requirements, also apply when eddy current examination, in accordance with Article 8, is required by a referencing Code Section.

(c) Definitions of terms for eddy current examination appear in Article 1, Appendix I, Subsection B, Article 30 and Mandatory Appendix IV of this Article.

TABLE T-823 01
REQUIREMENTS OF AN EDDY CURRENT EXAMINATION PROCEDURE

Requirement (As Applicable)	Essential Variable	Non-Essential Variable
Frequency(s)	X	
Mode (Differential/Absolute)	X	
Minimum Fill Factor	X	
Probe Type	X	
Maximum Scanning Speed	X	
Scanning Technique (Automatic/Manual)		X
Material being examined	X	
Material Size/Dimensions	X	
Reference Standard	X	
Equipment Manufacturer/Model	X	
Scanning Equipment/Fixtures		X
Data Recording Equipment	X	
Cabling (Type and Length)	X	
Acquisition Software	X	
Analysis Software	X	

T-820 GENERAL

01 T-821 Performance

Tubes may be examined at the finish size, after the final anneal or heat treatment, or at the finish size, prior to the final anneal or heat treatment, unless otherwise agreed upon between the supplier and the purchaser. The procedure shall be qualified by demonstrating detection of discontinuities of a size equal to or smaller than those in the reference specimen described in T-833. Indications equal to or greater than those considered reportable by the procedure shall be processed in accordance with T-880.

01 T-822 Personnel Requirements

The user of this Article shall be responsible for assigning qualified personnel to perform eddy current examinations to the requirements of this Article. Personnel performing examinations shall be qualified as required by the referencing Code Section.

T-823 Procedure 01

T-823.1 Requirments. Eddy current or other electomagnetic examinations shall be performed in accordance with a written procedure, which shall, as a minimum contain the requirements listed in Table T-823. The written procedure shall establish a single value, or range of values, for each requirement.

T-823.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Table T-823 identified as an essential variable from the specified value, or range of values, shall require requalification of the written procedure. Where a range is specified for an essential variable, the bounding

values of the range shall be qualified by demonstration. A change of a requirement identified as a nonessential variable from the specified value, or range of values, does not require requalification of the written procedure. All changes of essential or nonessential variables from the value, or range of values, specified by the written procedure shall require revision of, or an addendum to, the written procedure.

01 **T-830 EQUIPMENT**

Equipment shall consist of electronic apparatus capable of energizing the test coil or probes with alternating currents of suitable frequencies and shall be capable of sensing the changes in the electromagnetic properties of the material. Output produced by this equipment may be processed so as to actuate signaling devices and/or to record examination data.

01 **T-831 Test Coils and Probes**

Test coils or probes shall be capable of inducing alternating currents into the material and sensing changes in the electromagnetic characteristics of the material. Test coils should be selected to provide the highest practical fill factor.

01 **T-832 Scanners**

Equipment used should be designed to maintain the material concentric within the coil, or to keep the probe centered within the tube and to minimize vibration during scanning. Maximum scanning speeds shall be based on the equipment's data acquisition frequency response or digitizing rate, as applicable.

01 **T-833 Reference Specimen**

The reference specimen material shall be processed in the same manner as the product being examined. It shall be the same nominal size and material type (chemical composition and product form) as the tube being examined. Ideally, the specimen should be a part of the material being examined. Unless specified in the referencing Code Section, the reference discontinuities shall be transverse notches or drilled holes as described in Standard Practice SE-243, Section 7, Calibration Standards.

T-840 REQUIREMENTS

T-841 Procedure Requirements

A written procedure, when required according to T-150, shall include at least the following:

(a) frequency

(b) type of coil or probe (e.g., differential coil)

(c) type of material and sizes to which applicable

(d) reference specimen notch or hole size

(e) additional information as necessary to permit retesting

T-850 TECHNIQUE 01

Specific techniques may include special probe or coil designs, electronics, calibration standards, analytical algorithims and/or display software. Techniques, such as channel mixes, may be used as necessary to suppress signals produced at the ends of tubes. Such techniques shall be in accordance with requirements of the referencing Code Section.

T-860 CALIBRATION

T-861 Performance Verification 01

Performance of the examination equipment shall be verified by the use of the reference specimen as follows:

(a) As specified in the written procedure:

(1) at the beginning of each production run of a given diameter and thickness of a given material;

(2) at the end of the production run;

(3) at any time that malfunctioning is suspected.

(b) If, during calibration or verification, it is determined that the examination equipment is not functioning properly, all of the product tested since the last calibration or verification shall be re-examined.

(c) When requalification of the written procedure as required in T-823.2.

T-862 Calibration of Equipment 01

(a) Frequency of Calibration. Eddy current instrumentation shall be calibrated at least once a year, or whenever the equipment has been subjected to a major electronic repair, periodic overhaul, or damage. If equipment has not been in use for a year or more, calibration shall be done prior to use.

(b) Documentation. A tag or other form of documentation shall be attached to the eddy current equipment with dates of the calibration and calibration due date.

01 **T-870 EXAMINATION**

Tubes are examined by passing through an encircling coil, or past a probe coil with the apparatus set up in accordance with the written procedure. Signals produced by the examination are processed and evaluated. Data may be recorded for post-examination analysis or stored for archival purposes in accordance with the procedure. Outputs resulting from the evaluation may be used to mark and/or separate tubes.

01 **T-880 EVALUATION**

Evaluation of examination results for acceptance shall be as specified in the written procedure and in accordance with the referencing Code Section.

01 **T-890 DOCUMENTATION**

01 **T-891 Examination Reports**

A report of the examination shall contain the following information:

(a) tube material specification, diameter, and wall thickness condition

(b) coil or probe manufacturer, size and type

(c) mode of operation (absolute, differential, etc.)

(d) examination frequency or frequencies

(e) manufacturer, model, and serial number of eddy current equipment

(f) scanning speed

(g) examination procedure number and revision

(h) calibration standard and serial number

(i) identity of examination personnel, and, when required by the referencing Code Section, qualification level

(j) date of inspection

(k) list of acceptable material

(l) date and time of qualification

(m) results of requalification (as applicable)

T-892 Documentation of Performance Demonstration 01

When required by the referencing Code Section, performance demonstrations shall be documented.

ARTICLE 8 — APPENDIX I
EDDY CURRENT EXAMINATION METHOD FOR INSTALLED NONFERROMAGNETIC HEAT EXCHANGER TUBING

I-800 INTRODUCTION

I-810 SCOPE

This Appendix defines the eddy current (ET) examination method and equipment requirements applicable to installed nonferromagnetic heat exchanger tubing. When specified by the referencing Code Section, the eddy current techniques described in this Appendix shall be used. The methods and techniques described in this Appendix are intended to detect and quantify degradation in the tubing.

I-820 GENERAL REQUIREMENTS

(a) The basis frequency ET examination is required and shall be done in accordance with I-862.

(b) The requirements for test equipment and examination procedures shall be in accordance with I-830.

(c) Calibrations shall be done in accordance with I-860.

(d) Examination shall be done in accordance with I-870.

I-830 EQUIPMENT

Eddy current nondestructive testing equipment capable of operation in the differential mode or the absolute mode, or both, shall be used for this examination. A device for recording data, real time, in a format suitable for evaluation and for archival storage, shall be provided when required by the referencing Code Section.

I-831 Frequency of Calibration

Electronic instrumentation of the eddy current system shall be calibrated at least once a year or whenever the equipment has been overhauled or repaired as a result of malfunction or damage.

I-850 TECHNIQUE

Single frequency or multiple frequency techniques are permitted for this examination. Upon selection of the test frequency(s) and after completion of calibration, the probe shall be inserted into the tube where it is extended or positioned to the region of interest. Resulting eddy current signals at each of the individual frequencies shall be recorded for review, analysis, and final disposition.

I-860 CALIBRATION

I-861 Calibration Tube Standards

The calibration tube standard shall be manufactured from a length of tubing of the same nominal size and material type (chemical composition and product form) as that to be examined in the vessel. The intent of this reference standard is to establish and verify system response. The standard shall contain calibration discontinuities as follows.

(a) A single hole drilled 100% through the wall 0.052 in. (1.32 mm) diameter for $\frac{3}{4}$ in. (19 mm) O.D. tubing and smaller and 0.067 in. (1.70 mm) diameter for larger tubing.

(b) Four flat bottom holes, $\frac{3}{16}$ in. (4.8 mm) diameter, spaced 90 deg. apart in a single plane around the tube circumference, 20% through the tube wall from the O.D.

(c) A $\frac{1}{16}$ in. (1.6 mm) wide, 360 deg. circumferential groove, 10% through from the inner tube surface (optional).

(d) All calibration discontinuities shall be spaced so that they can be identified from each other and from the end of the tube.

(e) Each standard shall be identified by a serial number.

(f) The depth of the calibration discontinuities, at their center, shall be accurate to within ±20% of the specified depth or ±0.003 in. (±0.08 mm), whichever is smaller. All other dimensions shall be accurate to 0.010 in. (0.25 mm).

(g) The dimensions of the calibration discontinuities and the applicable ET system response shall become part of the permanent record of the standard.

I-862 Basis Frequency[1] Calibration Procedure

The examination system shall be calibrated utilizing the standard described in I-861.

(a) Basis Frequency Calibration Using Differential Bobbin Coil Technique

(1) Adjust the ET instrument for a basis frequency chosen so that the phase angle of a signal from the four 20% flat bottom holes is between 50 deg. and 120 deg. rotated clockwise from the signal of the through-the-wall hole (Fig. I-862-1).

(2) The trace display for the four 20% flat bottom holes shall be generated, when pulling the probe, in the directions illustrated in Fig. I-862-1: down and to the left first, followed by an upward motion to the right, followed by a downward motion returning to the point of origin.

(3) The sensitivity shall be adjusted to produce a minimum peak-to-peak signal from the four 20% flat bottom holes of 30% of the full scale horizontal presentation with the oscilloscope sensitivity set at 1 V per division.

(4) Adjust the phase or rotation control so that the signal response due to probe motion, or the 10% deep circumferential inside diameter groove, or both, is positioned along the horizontal axis of the display ±5 deg. The responses from the calibration holes shall be maintained as described in (a)(1), (2), and (3) above.

(b) Basis Frequency Calibration Using Absolute Bobbin Coil Technique

(1) Adjust the ET instrument for a basis frequency so that the phase angle between a line drawn from the origin to the tip of the response from the through-the-wall hole and the horizontal axis is approximately 40 deg. The phase angle formed by a line drawn from the origin to the tip of the response of the four 20% flat bottom holes and the through-the-wall response line is between 50 deg. and 120 deg. (see Fig. I-862-2).

(2) The sensitivity shall be adjusted to produce a minimum origin-to-peak signal from the four 20% flat bottom holes of 30% of the full scale horizontal presentation with the oscilloscope sensitivity set at 1 V per division.

(3) Adjust the phase or rotation control so that the signal response due to probe rotation, or the 10% deep circumferential inside diameter groove, or both, is positioned along the horizontal axis of the display ±5 deg. The response of the calibration reference shall be maintained as described in (b)(1) and (2) above.

(4) The response may be rotated to the upper quadrants of the display at the option and convenience of the operator.

(5) Repeat withdrawing the probe through the calibration tube standard at the probe speed selected for the examination. Record the responses of the applicable calibration discontinuities. Ascertain that they are clearly

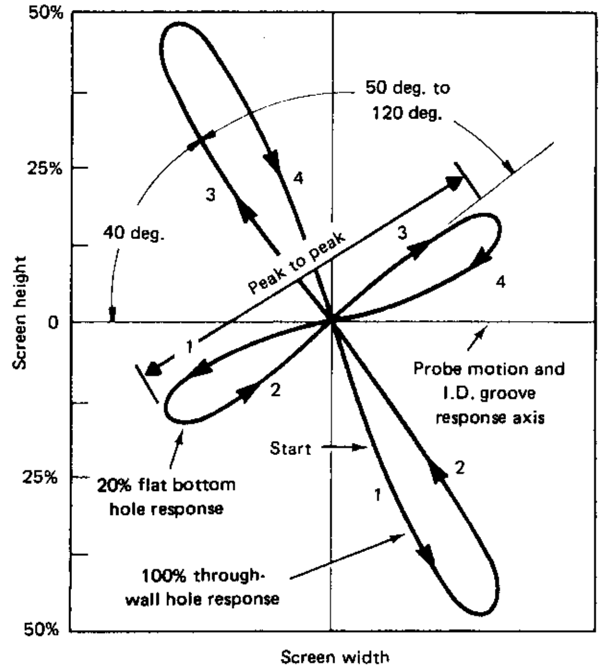


FIG. I-862-1 TYPICAL SIGNAL RESPONSE FROM A PROPERLY CALIBRATED DIFFERENTIAL BOBBIN COIL PROBE SYSTEM

[1] The basis frequency is that test frequency selected for the examination which provides responses from the 20% flat bottom holes and the 100% through-the-wall hole references in the calibration tube standard that have a phase angle difference between 50 deg. and 120 deg.

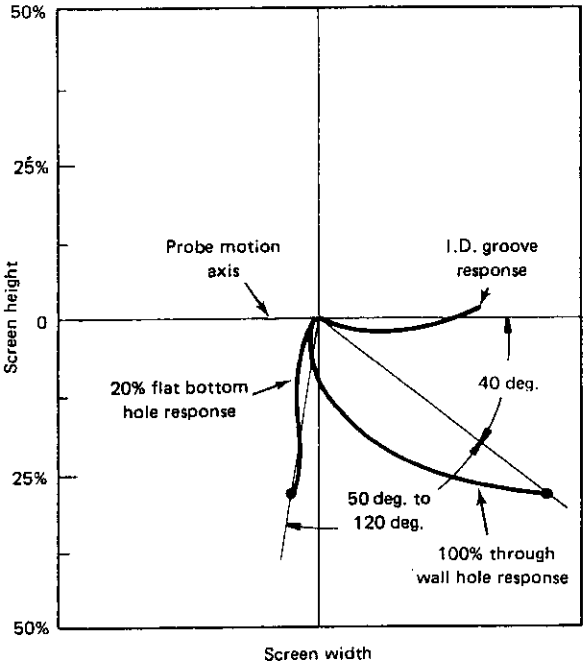


FIG. I-862-2 TYPICAL SIGNAL RESPONSE FROM A PROPERLY CALIBRATED ABSOLUTE BOBBIN COIL PROBE SYSTEM

indicated by the instrument and are distinguishable from each other as well as from probe motion signals.

I-863 Auxiliary Frequency(s) Calibration Procedure

(a) Auxiliary frequency(s) may be used to examine the tube wall. Reference standards other than that specified in I-861 may be used to establish examination specific sensitivity settings and an impedance plane phase reference.

(b) Auxiliary frequency(s) may be combined (mixed) with the basis frequency or with each other for extraneous variable suppression. When auxiliary frequency(s) are combined with the basis frequency for extraneous variable suppression, the basis frequency shall meet the requirements of I-862.

(c) Reference standards simulating the extraneous variables shall be used to establish mixing parameters. Auxiliary frequency response to the extraneous variable reference standard, or basis frequency response to the extraneous variable reference standard, or both, shall be a part of the calibration record.

(d) Repeat withdrawing the probe through the calibration standard at the probe speed selected for examination. Record the auxiliary frequency response of the applicable reference discontinuities.

(e) The basis frequency and auxiliary frequencies shall be recorded.

I-864 Calibration Confirmation

(a) Calibration shall include the complete ET examination system. Any change of probe, extension cables, ET instrument, recording instruments, or any other parts of the ET examination system hardware shall require recalibration.

(b) The system calibration hardware shall be confirmed as required by the referencing Code Section.

(c) Should the system be found to be out of calibration (as defined in I-862) the equipment shall be recalibrated. The recalibration shall be noted on the recording. The data analyst shall determine which tubes, if any, shall be re-examined.

I-865 Correlation of Signals to Estimate Depth of Discontinuities

The depth of discontinuities is primarily shown by the phase angle of the ET signal they produce. A relationship of reference comparator depths versus signal phase angle shall be developed for the examination being performed (see Fig. I-865-1). The following reference comparators may be used.

(a) The reference comparators shall be manufactured from a length of tubing of the same nominal size (diameter and wall thickness) and material (chemical composition and product form) as the tubes being examined.

(b) The reference comparators may be flat bottom holes drilled to varying depths.

(c) The drilled holes in the calibration standard (see I-861) may be used to establish this relationship where additional depths are required.

(d) The tolerance for the dimensions of the flat bottom holes shall be the same as those specified for the calibration tube standards [see I-861(g)].

(e) Except for the holes specified in (f)(1) below, all references shall be far enough apart to avoid interference between signals.

(f) When drilled holes are used, the dimensions shall be as follows:

(1) four flat bottom drill holes, $^{3}/_{16}$ in. (4.8 mm) diameter, 20% through the wall [same as the calibration tube standard (b) in I-861(b)];

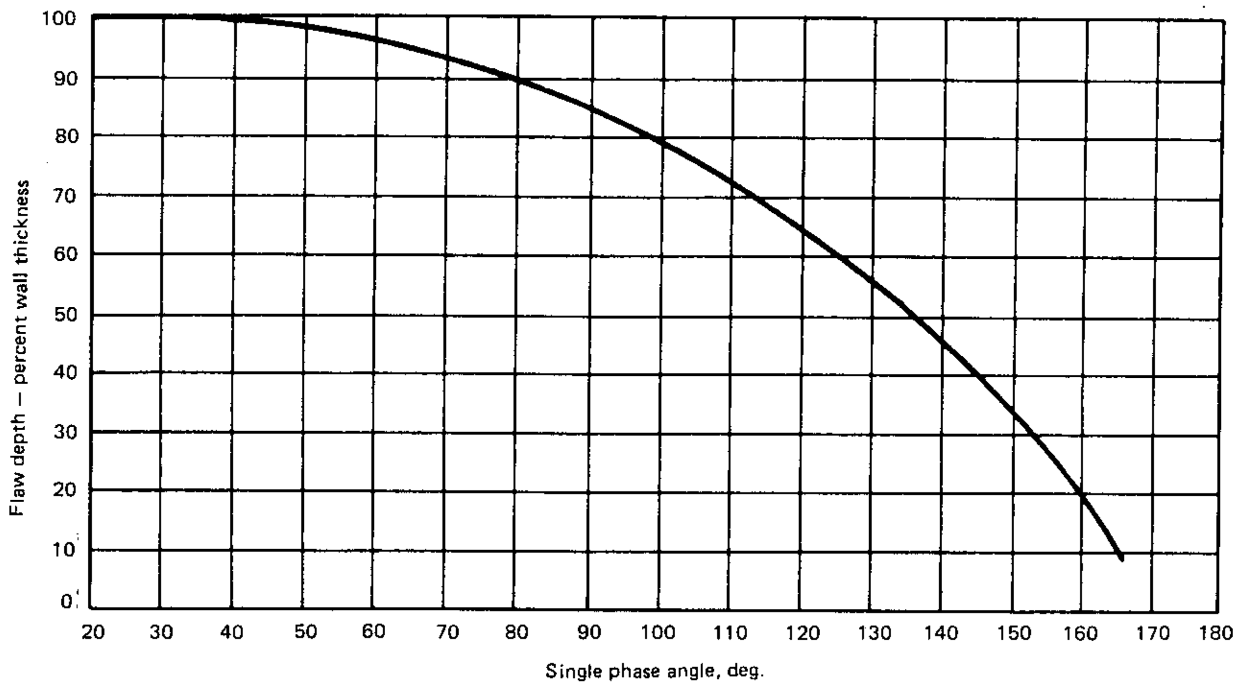


FIG. I-865-1 PHASE ANGLE vs FLAW DEPTH INCONEL TUBE, 400 kHz (TYPICAL 0.050 in. WALL TUBE)

(2) one flat bottom drill hole, $^3/_{16}$ in. (4.8 mm) in diameter × 40% through the wall from the outside surface;

(3) one flat bottom drill hole, $^7/_{64}$ in. (2.8 mm) in diameter × 60% through the wall from the outside surface;

(4) one flat bottom drill hole, $^5/_{64}$ in. (2.0 mm) in diameter × 80% through the wall from the outside surface;

(5) one through-the-wall drill hole [same as the calibration tube standard in I-861(a)].

(g) Other reference comparators may be used, provided that they can be demonstrated to be comparable to the intended discontinuity to be evaluated.

(h) Signal amplitude may be used to estimate depth for defects, which exhibit a known regularity in their growth history. Standards representative of the defect shall be used to generate an amplitude versus depth calibration curve.

I-870 EXAMINATION

I-871 General

Data shall be recorded as the probe traverses the tube.

I-872 Probe Speed

The nominal probe speed during examination shall not exceed 14 in./sec (356 mm/s). Higher probe speeds may be used if system frequency response and sensitivity to the applicable calibration standards described in I-861 can be demonstrated.

I-880 EVALUATION

I-881 General

The evaluation of examination data shall be made in accordance with the referencing Code Section.

I-890 DOCUMENTATION

I-891 Procedure Requirements

When required by the referencing Code Section, Eddy Current (ET) examinations shall be performed in accordance with a written procedure. Each procedure shall include at least the following information:

(a) tube material, diameter, and wall thickness;

(b) size and type of probes;

(c) mode of operation (differential or absolute or both);

(d) examination frequency or frequencies;

(e) manufacturer and model of ET equipment;

(f) scanning speed during examination;

(g) examination technique, i.e., hand probe, mechanized probe drive, remote control fixture, etc.;

(h) calibration procedure and calibration tube standards;

(i) data recording equipment and procedures;

(j) procedure for interpretation of results;

(k) additional information as necessary to describe the examination.

ARTICLE 8 — APPENDIX II
EDDY CURRENT EXAMINATION OF NONFERROMAGNETIC HEAT EXCHANGER TUBING

II-810 SCOPE

This Appendix provides the requirements for bobbin coil, multifrequency, multiparameter, Eddy Current examination for nonferromagnetic heat exchanger tubing.

II-820 GENERAL

This Appendix also provides the methodology for examining nonferromagnetic, heat exchanger tubing using the eddy current method and bobbin coil technique. By scanning the tubing from the boreside, information will be obtained from which the condition of the tubing will be determined. Scanning is generally performed with a bobbin coil attached to a flexible shaft driven by a motorized device. Results are obtained by evaluating data recorded during scanning.

II-820.1 General Requirements

II-820.1.1 Procedure Requirements. Examinations shall be conducted in accordance with a written procedure. Each procedure shall include the following information:

(a) tube material, diameter and wall thickness;

(b) size and type of probes, including manufacturer's name, description or part number, and length of probe and probe extension cables;

(c) examination frequencies;

(d) manufacturer and model of eddy current equipment;

(e) scanning direction and speed during examination (insertion, retraction, or both — from inlet or outlet end);

(f) inspection technique, e.g., hand probe, mechanized probe driven, remote control fixture;

(g) description of calibration procedure and calibration standards;

(h) description of data recording equipment and procedures;

(i) procedure for analysis of examination results and applicable criteria for reportable indications;

(j) procedure for reporting examination results, e.g., 3 digit codes or reference points;

(k) personnel requirements;

(l) fixture location verification.

II-820.1.2 Personnel Requirements. Nondestructive examination personnel shall be qualified in accordance with the requirements of the referencing Code Section.

II-830 EQUIPMENT

II-830.1 Data Acquisition System

II-830.1.1 General System Requirements

(a) The eddy current instrument shall have the capability of generating multiple frequencies simultaneously or multiplexed and be capable of multiparameter signal combination. In the selection of frequencies, consideration shall be given to optimizing flaw detection and characterization.

(b) The outputs from the eddy current instrument shall provide phase and amplitude information.

(c) The eddy current equipment shall be capable of detecting and recording dimensional changes, metallurgical changes and foreign material deposits, and responses from flaws originating on either tube wall surface.

II-830.2 Analog Data Acquisition System

II-830.2.1 Eddy Current Instrument

(a) The frequency response of the outputs from the eddy current instrument shall be constant within ±2% of full scale from dc to F_{max}, where F_{max} (Hz) is equal to 10 (Hz-sec/in.) [0.4 (Hz-sec/mm)] times maximum probe travel speed (in./sec).

(b) Eddy current signals shall be displayed as two-dimensional patterns by use of an X-Y storage oscilloscope or equivalent.

(c) The frequency response of the instrument output shall be constant within ±2% of the input value from

dc to F_{max}, where F_{max} (Hz) is equal to 10 (Hz-sec/in.) [0.4 (Hz-sec/mm)] times maximum probe travel speed.

II-830.2.2 Magnetic Tape Recorder

(a) The magnetic tape recorder shall be capable of recording and playing back eddy current signal data from all test frequencies and shall have voice logging capability.

(b) The frequency response of the magnetic tape recorder outputs shall be constant within ±10% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 (Hz-sec/in.) times maximum probe travel speed.

(c) Signal reproducibility from input to output shall be within ±5%.

II-830.2.3 Strip Chart Recorder

(a) Strip chart recorders used during the examination shall have at least 2 channels.

(b) The frequency response of the strip chart recorder shall be constant within ±20% of full scale from dc to F_{max}, where F_{max} (Hz) is equal to 10 (Hz-sec/in.) [0.4 (Hz-sec/mm)] times maximum probe travel speed.

II-830.3 Digital Data Acquisition System

II-830.3.1 Eddy Current Instrument

(a) At the scanning speed to be used, the sampling rate of the instrument shall result in a minimum digitizing rate of 30 samples per in. (25 mm) of examined tubing, using dr = sr/ss, where dr is the digitizing rate in samples per in., sr is the sampling rate in samples per sec or Hz, and ss is the scanning speed in in. per sec.

(b) The digital eddy current instrument shall have a minimum resolution of 12 bits per data point.

(c) The frequency response of the outputs of analog portions of the eddy current instrument shall be constant within ±2% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 (Hz-s/in.) [0.4 (Hz-sec/mm)] times maximum probe travel speed.

(d) The display shall be selectable so that the examination frequency or mixed frequencies can be presented as a Lissajous pattern.

(e) The Lissajous display shall have a minimum resolution of 7 bits full scale.

(f) The strip chart display shall be capable of displaying at least 2 traces.

(g) The strip chart display shall be selectable so either the X or Y component can be displayed.

(h) The strip chart display shall have a minimum resolution of 6 bits full scale.

II-830.3.2 Recording System

(a) The recording system shall be capable of recording and playing back all acquired eddy current signal data from all test frequencies.

(b) The recording system shall be capable of recording and playing back text information.

(c) The recording system shall have a minimum resolution of 12 bits per data point.

II-830.4 Bobbin Coils

II-830.4.1 General Requirements

(a) Bobbin coils shall be able to detect calibration standard discontinuities.

(b) Bobbin coils shall have sufficient bandwidth for operating frequencies selected for flaw detection and sizing.

II-830.5 Data Analysis System

II-830.5.1 General System Requirements

(a) The data analysis system shall be capable of displaying eddy current signal data from all test frequencies.

(b) The system shall have multiparameter mixing capability.

(c) The system shall be capable of maintaining the identification of each tube recorded.

(d) The system shall be capable of measuring phase angles in increments of one degree or less.

(e) The system shall be capable of measuring amplitudes to the nearest 0.1 volt.

II-830.6 Analog Data Analysis System

II-830.6.1 Display. Eddy current signals shall be displayed as Lissajous patterns by use of an X-Y storage display oscilloscope or equivalent. The frequency response of the display device shall be constant within ±2% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 (Hz-sec/in.) [0.4 (Hz-sec/mm)] times maximum probe travel speed.

II-830.6.2 Recording System

(a) The magnetic tape recorder shall be capable of playing back the recorded data.

(b) The frequency response of the magnetic tape recorder outputs shall be constant within ±10% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 (Hz-sec/in.) times maximum probe travel speed (in./sec).

(c) Signal reproducibility input to output shall be within ±5%.

II-830.7 Digital Data Analysis System

II-830.7.1 Display

(a) The analysis display shall be capable of presenting recorded eddy current signal data and text information.

(b) The analysis system shall have a minimum resolution of 12 bits per data point.

(c) The Lissajous pattern display shall have a minimum resolution of 7 bits full scale.

(d) The strip chart display shall be selectable so either the X or Y component of any examination frequency or mixed frequencies can be displayed.

(e) The strip chart display shall have a minimum resolution of 6 bits full scale.

II-830.7.2 Recording System

(a) The recording system shall be capable of playing back all recorded eddy current signal data and text information.

(b) The recording system shall have a minimum resolution of 12 bits per data point.

II-830.8 Hybrid Data Analysis System

(a) For a hybrid system using both digital elements and some analog elements, individual elements shall meet II-830.1 and either II-830.2 or II-830.3, as applicable.

(b) If analog to digital or digital to analog converters are used, the frequency response of the analog element outputs shall be constant within ±5% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 (Hz-sec/in.) [0.4 (Hz-sec/mm)] times maximum probe travel speed.

II-840 REQUIREMENTS

II-840.1 General Requirements

(a) The eddy current signal data from all test frequencies shall be recorded on the recording media as the probe traverses the tube.

(b) The sensitivity for the differential bobbin coil technique shall be sufficient to produce a response from the through-wall holes with a minimum vertical amplitude of 50% of the full Lissajous display height.

II-840.2 Probe Traverse Speed. The traverse speed shall not exceed that which provides adequate frequency response and sensitivity to the applicable calibration discontinuities.

II-840.3 Fixture Location Verification

(a) The ability of the fixture to locate specific tubes shall be verified visually and recorded upon installation of the fixture and before relocating or removing the fixture.

(b) When the performance of fixture location reveals that an error has occurred in the recording of probe verification location, the tubes examined since the previous location verification shall be re-examined.

II-840.4 Automated Data Screening System. When automated eddy current data screening systems are used, each system shall be qualified in accordance with a written procedure.

II-860 CALIBRATION

II-860.1 Equipment Calibration

II-860.1.1 Analog Equipment 01

The following shall be verified by annual calibration.

(a) The oscillator output frequency to the drive coil shall be within ±5% of its indicated frequency.

(b) The vertical and horizontal linearity of the cathode ray tube (CRT) display shall be within ±10% of the deflection of the input voltage.

(c) The CRT vertical and horizontal trace alignment shall be within ±2 deg. of parallel to the graticule lines.

(d) The ratio of the output voltage from the tape recorder shall be within ±5% of the input voltage for each channel of the tape recorder.

(e) The chart speed from the strip chart recorder shall be within ±5% of the indicated value.

(f) Amplification for all channels of the eddy current instrument shall be within 5% of the mean value, at all sensitivity settings, at any single frequency.

(g) The two output channels of the eddy current instrument shall be orthogonal within ±3 deg. at the examination frequency.

II-860.1.2 Digital Equipment. Analog elements of digital equipment shall be calibrated in accordance with II-860.1.1. Digital elements need not be calibrated.

II-860.2 Calibration Standards

II-860.2.1 General Requirements. Calibration standards shall conform to the following:

(a) Calibration standards shall be manufactured from a tubing of the same material specification, same heat treatment, and same nominal size as that to be examined in the vessel.

(b) Tubing calibration standard materials heat treated differently from the tubing to be examined may be used when signal responses from the discontinuities described in II-860.2.2 are demonstrated to the Inspector to be equivalent in both the calibration standard and tubing of the same heat treatment as the tubing to be examined.

(c) As an alternative to (a) and (b), calibration standards fabricated from UNS Alloy N06600 shall be manufactured from a length of tubing of the same material specification and same nominal size as that to be examined in the vessel.

(d) Discontinuities in calibration standards shall be spaced axially so they can be differentiated from each other and from the end of the tube. The as-built dimensions of the discontinuities and the applicable Eddy Current equipment response shall become part of the permanent record of the standard.

II-860.2.2 Calibration Standards for Differential and Absolute Bobbin Coil

(a) Calibration standards shall contain:

(1) One or both through-wall holes as follows:

(a) A 0.052 in. (1.32 mm) diameter hole for tubing with diameters of 0.750 in. (19 mm) and less, or a 0.067 in. (1.70 mm) hole for tubing with diameters greater than 0.750 in. (19 mm).

(b) Four holes spaced 90 deg. apart in a single plane around the tube circumference, 0.026 in. (0.66 mm) diameter for tubing with diameters of 0.750 in. (19 mm) and less and 0.033 in. (0.84 mm) diameter for tubing with diameters greater than 0.750 in. (19 mm).

(2) A flat-bottom hole 0.109 in. (2.8 mm) diameter, 60% through the tube wall from the outer surface.

(3) A flat-bottom hole 0.187 in. (4.8 mm) diameter, 40% through the tube wall from the outer surface.

(4) Four flat-bottom holes 0.187 in. (4.8 mm) diameter, spaced 90 deg. apart in a single plane around the tube circumference, 20% through the tube wall from the outer surface.

(b) The depth of the artificial discontinuities, at their center, shall be within ±20% of the specified depth or ±0.003 in. (±0.08 mm), whichever is less. All other dimensions shall be within ±0.03 in. (±0.8 mm).

(c) All artificial discontinuities shall be sufficiently separated to avoid interference between signals, except for the holes specified in (a)(1)(b) and (a)(4).

II-860.3 Analog System Calibration

II-860.3.1 Differential Bobbin Coil Technique

(a) The sensitivity shall be adjusted to produce a minimum peak-to-peak signal of 4 volts from the four 20% flat-bottom holes or 6 volts from the four through-wall drilled holes.

(b) The phase or rotation control shall be adjusted so the signal response due to the through-wall hole forms down and to the right first as the probe is withdrawn from the standard holding the signal response from the probe motion horizontal.

(c) Withdraw the probe through the calibration standard at the nominal examination speed. Record the responses of the applicable calibration discontinuities. The responses shall be clearly indicated by the instrument and shall be distinguishable from each other as well as from probe motion signals.

II-860.3.2 Absolute Bobbin Coil Technique

(a) The sensitivity shall be adjusted to produce a minimum origin-to-peak signal of 2 volts from the four 20% flat-bottom holes or 3 volts from the four through-wall drilled holes.

(b) Adjust the phase or rotation control so that the signal response due to the through-wall hole forms up and to the left as the probe is withdrawn from the standard holding the signal response from the probe motion horizontal.

(c) Withdraw the probe through the calibration standard at the nominal examination speed. Record the responses of the applicable calibration discontinuities. The responses shall be clearly indicated by the instrument and shall be distinguishable from each other as well as from probe motion signals.

II-860.4 Digital System Calibration. When the eddy current examination information is digitized and recorded for off-line analysis and interpretation, the system calibration phase and amplitude settings shall be performed off-line by the data analyst. Phase and amplitude settings shall be such that the personnel acquiring the data can clearly discern that the eddy current instrument is working properly.

II-860.4.1 System Calibration Verification

(a) Calibration shall include the complete eddy current examination system. Any change of probe, extension cables, eddy current instrument, recording instruments, or any other parts of the eddy current examination system hardware shall require recalibration.

(b) System calibration verification shall be performed and recorded at the beginning and end of each unit of data storage of the recording media.

(c) Should the system be found to be out of calibration (as defined in II-860.3), the equipment shall be recalibrated. The recalibration shall be noted on the recording and the data analyst shall determine which tubes, if any, shall be reexamined.

II-880 EVALUATION

II-880.1 Data Evaluation. Data shall be evaluated in accordance with the requirements of this Article.

II-880.2 Means of Determining Indication Depth. For indication types that must be reported in terms of depth, a means of correlating the indication depth with the signal amplitude or phase shall be established. The means of correlating the signal amplitude or phase with the indication depth shall be based on the basic calibration standard or other representative standards that have been qualified. This shall be accomplished by using curves, tables, or software.

II-880.3 Frequencies Used for Data Evaluation. All indications shall be evaluated. Indication types, which must be reported, shall be characterized using the frequencies or frequency mixes that were qualified.

II-890 DOCUMENTATION

II-890.1 Reporting

II-890.1.1 Criteria. Indications reported in accordance with the requirements of this Article shall be described in terms of the following information, as a minimum:

(a) location along the length of the tube and with respect to the support members

(b) depth of the indication through the tube wall, when required by this Article

(c) signal amplitude

(d) frequency or frequency mix from which the indication was evaluated

II-890.1.2 Depth. The maximum evaluated depth of flaws shall be reported in terms of percentage of loss of tube wall. When the loss of tube wall is determined by the analyst to be less than 20%, the exact percentage of tube wall loss need not be recorded, i.e., the indication may be reported as being less than 20%.

II-890.1.3 Non-Quantifiable Indications. A non-quantifiable indication is a reportable indication that cannot be characterized. The indication shall be considered a flaw until otherwise resolved.

II-890.1.4 Support Members

II-890.1.4.1 Location of Support Members. The location of support members used as reference points for the eddy current examination shall be verified by fabrication drawings or the use of a measurement technique.

II-890.2 Records

II-890.2.1 Record Identification. The recording media shall contain the following information within each unit of data storage:

(a) owner

(b) plant site

(c) heat exchanger identification

(d) data storage unit number

(e) date of examination

(f) serial number of the calibration standard

(g) operator's identification and certification level

(h) examination frequencies

(i) lengths of probe and probe extension cables

(j) size and type of probes

(k) probe manufacturer's name and manufacturer's part number or probe description

II-890.2.2 Tube Identification

(a) Each tube examined shall be identified on the applicable unit of data storage

(b) The method of recording the tube identification shall correlate tube identification with corresponding recorded tube data.

II-890.2.3 Reporting

(a) The Owner or his agent shall prepare a report of the examinations performed. The report shall be prepared, filed, and maintained in accordance with the referencing Code Section. Procedures and equipment used shall be identified sufficiently to permit comparison of the examination results with new examination results run at a later date. This shall include initial calibration data for each eddy current examination system and subsequent rechecks.

(b) The report shall include a record indicating the tubes examined (this may be marked on a tubesheet sketch or drawing), any scanning limitations, the location and depth of each reported flaw, and the identification and certification level of the operators and data evaluators that conducted each examination or part thereof.

(c) Tubes that are to be repaired or removed from service, based on eddy current examination data, shall be identified.

ARTICLE 8 — APPENDIX III
EDDY CURRENT (ET) EXAMINATION ON COATED FERRITIC MATERIALS

01 III-810 SCOPE

(a) This Appendix provides the Eddy Current examination methodology and equipment requirements applicable for performing Eddy Current examination on coated ferritic materials.

(b) Article 1, General Requirements, also applies when Eddy Current examination of coated ferritic materials is required. Requirements for written procedures, as specified in Article 8, shall apply, as indicated.

(c) ASTM D 1186, Standard for Magnetic Thickness Measurement of Coatings, may be used as a procedure for measuring the thickness of conductive coatings.

III-820 GENERAL

III-821 Personnel Qualification

NDE personnel shall be qualified in accordance with the requirements of the referencing Code Section.

01 III-822 Procedure

The requirements of T-823 shall apply. The type of coating and maximum coating thickness shall be essential variables.

01 III-823 Procedure Demonstration

The procedure shall be demonstrated to the satisfaction of the Inspector in accordance with requirements of the referencing Code Section.

III-830 EQUIPMENT

The ET system shall include phase and amplitude display.

III-850 TECHNIQUE 01

III-851 Coating Thickness Measurement 01

The performance of examinations shall be preceded by measurement of the coating thickness in the areas to be examined. If the coating is nondconductive, an Eddy Current technique may be used to measure the coating thickness. If the coating is conductive, a magnetic coating thickness technique may be used in accordance with ASTM D 1186. Coating thickness measurement shall be used in accordance with the equipment manufacturer's instructions. Coating thickness measurements shall be taken at the intersections of a 2 in. (51 mm) maximum grid pattern over the area to be examined. The thickness shall be the mean of three separate readings within $\frac{1}{4}$ in. (6 mm) of each intersection.

III-852 Procedure Verification 01

(a) A qualification specimen is required. The material used for the specimen shall be the same specification and heat treatment as the coated ferromagnetic material to be examined. If a conductive primer was used on the material to be examined, the primer thickness on the procedure qualification specimen shall be the maximum allowed on the examination surfaces by the coating specification. Plastic shim stock may be used to simulate nonconductive coatings for procedure qualification. The thickness of the coating or of the alternative plastic shim stock on the procedure qualification specimen shall be equal to or greater than the maximum coating thickness measured on the examination surface.

(b) The qualification specimen shall include at least one crack. The length of the crack open to the surface shall not exceed the allowable length for surface flaws. The maximum crack depth in the base metal shall be between 0.020 and 0.040 in. (0.51 mm and 1.02 mm). In addition, if the area of interest includes weld metal, a 0.020 in. (0.51 mm) maximum depth crack is required in an as-welded and coated surface typical of the welds

to be examined. In lieu of a crack, a machined notch of 0.010 in. (0.25 mm) maximum width and 0.020 in. (0.51 mm) maximum depth may be used in the as-welded surface.

(c) Examine the qualification specimen first uncoated and then after coating to the maximum thickness to be qualified. Record the signal amplitudes from the qualification flaws.

(d) Using the maximum scanning speed, the maximum scan index, and the scan pattern specified by the procedure, the procedure shall be demonstrated to consistently detect the qualification flaws through the maximum coating thickness regardless of flaw orientation (e.g., perpendicular, parallel, or skewed to the scan direction). The signal amplitude from each qualification flaw in the coated qualification specimen shall be at least 50% of the signal amplitude measured on the corresponding qualification flaw prior to coating.

III-870 EXAMINATION

(a) Prior to the examination, all loose, blistered, flaking, or peeling coating shall be removed from the examination area.

(b) When conducting examinations, areas of suspected flaw indications shall be confirmed by application of another surface or volumetric examination method. It may be necessary to remove the surface coating prior to performing the other examination.

III-890 DOCUMENTATION 01

III-891 Examination Report 01

The report of examination shall contain the following information:

(a) a procedure identification and revision

(b) examination personnel identity, and, when required by the referencing Code Section, qualification level

(c) date of examination

(d) results of examination and related sketches or maps of rejectable indications

(e) identification of part or component examined

III-892 Performance Demonstration Report 01

Performance demonstrations shall be documented and contain the following information:

(a) identification of the procedure

(b) identification of personnel performing and witnessing the qualification

(c) descriptions and drawings or sketches of the qualification specimen and calibration reference standards, including coating thickness measurement and flaw dimensions

(d) calibration sensitivity details

(e) qualification results, including maximum coating thickness and flaws detected

ARTICLE 8 — APPENDIX IV GLOSSARY OF TERMS FOR EDDY CURRENT EXAMINATION

IV-810 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms related to Eddy Current examination, which appears in Article 8.

IV-820 GENERAL REQUIREMENTS

(a) This standard terminology for nondestructive examination ASTM E 1316 has been adopted by the Committee as SE-1316.

(b) SE-1316 Section 6, Electromagnetic Testing, provides the definitions of terms listed in IV-830(a).

(c) For general terms, such as *Interpretation, Flaw, Discontinuity, Evaluation,* etc., refer to Article 1, Mandatory Appendix I.

(d) Paragraph IV-830(b) provides a list of terms and definitions, which are in addition to SE-1316 and are Code specific.

IV-830 REQUIREMENTS

(a) The following SE-1316 terms are used in conjunction with this Article: *absolute coil, differential coils, eddy current, eddy current testing, frequency, phase angle, probe coil, reference standard, standard.*

(b) The following Code terms are used in conjunction with this Article.

bobbin coil — for inspection of tubing, a bobbin coil is defined as a circular inside diameter coil wound such that the coil is concentric with a tube during examination

text information — information stored on the recording media to support recorded eddy current data. Examples include tube and steam generator identification, operator's name, date of examination, and results.

unit of data storage — each discrete physical recording medium on which eddy current data and text information are stored. Examples include tape cartridge, floppy disk, etc.

ARTICLE 9

Table

Mandatory Appendix

ARTICLE 9
VISUAL EXAMINATION

01 **T-910 SCOPE**

(a) This Article contains methods and requirements for visual examination applicable when specified by a referencing Code Section. Specific visual examination procedures required for every type of examination are not included in this Article, because there are many applications where visual examinations are required. Some examples of these applications include nondestructive examinations, leak testing, in-service examinations and fabrication procedures.

(b) The requirements of Article 1, General Requirements, apply when visual examination, in accordance with Article 9, is required by a referencing Code Section.

(c) Definitions of terms for visual examination appear in Article 1, Appendix I – Glossary of Terms in Nondestructive Examination, and Article 9, Appendix I.

TABLE T-923 01
REQUIREMENTS OF A VISUAL EXAMINATION PROCEDURE

Requirement (As Applicable)	Essential Variable	Non-Essential Variable
Technique used	X	
Surface Conditions	X	
Surface preparation/cleaning		X
Method or Tool(s) required for Surface Preparation		X
Direct or Indirect Viewing method	X	
Special Illumination	X	
Equipment to be used		X
Sequence of performing examination		X
Data to be documented		X
Report Forms to be Completed		X
Personnel Qualifications	X	
Procedure Qualification Reference	X	

T-920 GENERAL

01 **T-921 Performance**

Visual examination to this Article, when required by the referencing Code Sections, shall be performed to a written procedure prepared by the user.

01 **T-922 Personnel Requirements**

The user of this Article shall be responsible for assigning qualified personnel to perform visual examinations to the requirements of this Article. At the option of the manufacturer, he may maintain one certification for each product, or several separate signed records based on the area or type of work, or both combined. Where impractical to use specialized visual examination personnel, knowledgeable and trained personnel, having limited qualifications, may be used to perform specific examinations, and to sign the report forms. Personnel performing examinations shall be qualified in accordance with requirements of the referencing Code Section.

T-923 Procedure 01

T-923.1 Requirements. Visual examinations shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table T-923. The written procedure shall establish a single value or range of values, for each requirement.

T-923.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Table T-923 identified as an essential variable from the specified value, or range of values, shall require requalification of the written procedure. Where a range is specified for an essential variable, the bounding values of the range shall be qualified by demonstration. A change of a requirement identified as a nonessential variable from the specified value, or range of values, does not require requalification of the written procedure. All changes of essential or nonessential variables from the value, or range of values specified by the written

procedure shall require revision of, or an addendum to, the written procedure.

01 T-930 EQUIPMENT

Equipment used for visual examination techniques, for example, direct, remote, or transluscent, shall have the capabilities as specified in the procedure. Capabilities include, but are not limited to viewing, magnifying, identifying, measuring, and/or recording observations in accordance with requirements of the referencing Code Section.

01 T-940 MISCELLANEOUS REQUIREMENTS

01 T-941 Procedure Requirements

The procedure shall contain or reference a report of what was used to demonstrate that the examination procedure was adequate. In general, a fine line $\frac{1}{32}$ in. (0.8 mm) or less in width, an artificial imperfection or a simulated condition, located on the surface or a similar surface to that to be examined, may be considered as a method for procedure demonstration. The condition or artificial imperfection should be in the least discernable location on the area surface to be examined to validate the procedure.

NOTE: T-941.3 is a non-essential variable (See Table T-923).

01 **T-941.1** Visual examination shall be performed in accordance with a written procedure.

T-941.2 A written procedure, when required in accordance with T-150, shall include at least the following:

(a) how visual examination is to be performed;

(b) type of surface condition and criteria for surface cleaning;

(c) cleaning instructions or reference to cleaning procedures:

(d) method or tool for surface preparation, if any;

(e) whether direct or remote viewing is used;

(f) special illumination, instruments, or equipment to be used, if any;

(g) sequence of performing examination, when applicable;

(h) data to be tabulated, if any;

(i) report forms or general statement to be completed.

T-941.3 In some instances it is preferable to relate the procedure to a specific component or surface such as the internal examination of a weld many feet from the open end of a tube or tubes of several sizes, but procedures may be in a general form applicable without adaptation to a variety of unlisted products or situations, thereby reducing the number of written procedures required.

T-941.4 The procedure shall contain or reference a report of what was used to demonstrate that the examination procedure was adequate. In general, a fine line $\frac{1}{32}$ in. (0.8 mm) or less in width, or some other artificial flaw located on the surface or a similar surface to that to be examined, may be considered a test method for this demonstration. The line or artificial flaw should be in the least discernible location on the area examined, to prove the procedure.

T-941.5 Substituting one equipment manufacturer's equipment for another, or changes in the details of test arrangement, will not require requalification.

T-942 Physical Requirements

Personnel shall have an annual vision test to assure natural or corrected near distance acuity such that they are capable of reading standard J-1 letters on standard Jaeger test type charts for near vision. Equivalent near vision tests are acceptable.

T-950 TECHNIQUE 01

T-951 Applications

Visual examination is generally used to determine such things as the surface condition of the part, alignment of mating surfaces, shape, or evidence of leaking. In addition, visual examination is used to determine a composite material's (translucent laminate) subsurface conditions.

T-952 Direct Visual Examination 01

Direct visual examination may usually be made when access is sufficient to place the eye within 24 in. (610 mm) of the surface to be examined and at an angle not less than 30 deg. to the surface to be examined. Mirrors may be used to improve the angle of vision, and aids such as a magnifying lens may be used to assist examinations. Illumination (natural or supplemental white light) for the specific part, component, vessel, or section thereof being examined is required. The minimum light intensity at the examination surface/site shall be 100 footcandles (1000 lux). The light source, technique used, and light level verification is required to be demonstrated one time, documented, and maintained on file. Personnel shall have an annual vision

test to assure natural or corrected near distance acuity such that they are capable of reading standard J-1 letters on standard Jaeger test type charts for near vision. Equivalent near vision tests are acceptable.

T-953 Remote Visual Examination

In some cases, remote visual examination may have to be substituted for direct examination. Remote visual examination may use visual aids such as mirrors, telescopes, borescopes, fiber optics, cameras, or other suitable instruments. Such systems shall have a resolution capability at least equivalent to that obtainable by direct visual observation.

01 T-954 Translucent Visual Examination

Translucent visual examination is a supplement of direct visual examination. The method of translucent visual examination uses the aid of artificial lighting, which can be contained in an illuminator that produces directional lighting. The illuminator shall provide light of an intensity that will illuminate and diffuse the light evenly through the area or region under examination. The ambient lighting must be so arranged that there are no surface glares or reflections from the surface under examination and shall be less than the light applied through the area or region under examination. The artificial light source shall have sufficient intensity to permit "candling" any translucent laminate thickness variations.

T-980 EVALUATION

T-980.1 All examinations shall be evaluated in terms of the acceptance standards of the referencing Code Section.

T-980.2 An examination checklist shall be used to plan visual examination and to verify that the required visual observations were performed. This checklist establishes minimum examination requirements and does not indicate the maximum examination which the Manufacturer may perform in process. 01

T-990 DOCUMENTATION 01

T-991 Report of Examination 01

T-991.1 A written report of the examination shall contain the following information:

(a) the date of the examination;

(b) procedure identification and revision used;

(c) technique used;

(d) results of the examination;

(e) examination personnel identity, and, when required by the referencing Code Section, qualification level;

(f) identification of the part or component examined.

T-991.2 Even though dimensions, etc., were recorded in the process of visual examination to aid in the evaluation, there need not be documentation of each viewing or each dimensional check. Documentation shall include all observation and dimensional checks specified by the referencing Code Section.

T-992 Performance Documentation 01

Documentation of performance demonstration shall be completed when required by the referencing Code Section.

T-993 Record Maintenance 01

Records shall be maintained as required by the referencing Code Section.

ARTICLE 9
MANDATORY APPENDIX

APPENDIX I — GLOSSARY OF TERMS FOR VISUAL EXAMINATION

I-910 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms related to Visual Examination which appear in Article 9.

01 I-920 GENERAL

(a) Article 30, SE-1316, Section 9, provides the definition of *footcandle (fc)*.

(b) Definitions of terms for visual examination and other methods appear in Article 1, Mandatory Appendix I, Glossary of Terms for Nondestructive Examination.

(c) The following Code terms are used in conjunction with Article 9:

artificial flaw — an intentional imperfection placed on the surface of a material to depict a representative flaw condition

auxiliary lighting — an artificial light source used as a visual aid to improve viewing conditions and visual perception

candling — see *translucent visual examination*

direct visual examination — a visual examination technique performed by eye and without any visual aids (excluding light source, mirrors, and/or corrective lenses)

enhanced visual examination — a visual examination technique using visual aids to improve the viewing capability, e.g., magnifying aids, borescopes, video probes, fiber optics, etc.

lux (Lx) — a unit of illumination equal to the direct illumination on a surface that is everywhere one meter from a uniform point source of one candle intensity or equal to one lumen per square meter

remote visual examination — a visual examination technique used with visual aids for conditions where the area to be examined is inaccessible for direct visual examination

surface glare — reflections of artificial light that interfere with visual examination

translucent laminate — a series of glass reinforced layers, bonded together, and having capabilities of transmitting light

translucent visual examination — a technique using artificial lighting intensity to permit viewing of translucent laminate thickness variations (also called candling)

visual examination — a nondestructive examination method used to evaluate an item by observation, such as: the correct assembly, surface conditions, or cleanliness of materials, parts, and components used in the fabrication and construction of ASME Code vessels and hardware

ARTICLE 10

Mandatory Appendices

Tables

Nonmandatory Appendix

ARTICLE 10
LEAK TESTING

T-1000 INTRODUCTION

01 T-1010 SCOPE

This Article describes methods and requirements for the performance of leak testing.

(a) When a leak testing method or technique of Article 10 is specified by a referencing Code Section, the leak test method or technique shall be used together with Article 1, General Requirements.

(b) Definition of terms used in this Article are in Mandatory Appendix VII of this Article.

(c) The test methods or techniques of these methods can be used for the location of leaks or the measurement of leakage rates.

The Nonmandatory Standards of Article 27 may be used in the preparation of leak test specifications. The specific test method(s) or technique(s) and Glossary of Terms of the methods in this Article are described in Mandatory Appendices I through X and Nonmandatory Appendix A as follows:

Appendix I — Bubble Test — Direct Pressure Technique

Appendix II — Bubble Test — Vacuum Box Technique

Appendix III — Halogen Diode Detector Probe Test

Appendix IV — Helium Mass Spectrometer Test — Detector Probe Technique

Appendix V — Helium Mass Spectrometer Test — Tracer Probe Technique

Appendix VI — Pressure Change Test

Appendix VII — Glossary of Terms

Appendix VIII — Thermal Conductivity Detector Probe Test

Appendix IX — Helium Mass Spectrometer Test — Hood Technique

Appendix X — Ultrasonic Leak Detector Test

Appendix A — Supplementary Leak Testing Formula Symbols

T-1020 GENERAL

01 T-1021 Procedure Requirements

Leak testing shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable:

(a) extent of the examination;

(b) type of equipment to be used for detecting leaks or measuring leakage rates;

(c) surface cleanliness preparation and type of equipment used;

(d) method or technique of the test that will be performed;

(e) temperature, pressure, gas, and percent concentration to be used.

T-1022 Referencing Code

For the leak testing method(s) or technique(s) specified by the referencing Code, the referencing Code Section shall then be consulted for the following:

(a) personnel qualification/certification

(b) technique(s)/calibration standards

(c) extent of examination

(d) acceptable test sensitivity or leakage rate

(e) report requirements

(f) retention of records

T-1030 EQUIPMENT

T-1031 Gages 01

(a) Gage Range. When dial indicating and recording pressure gage(s) are used in leak testing, they should preferably have the dial(s) graduated over a range of approximately double the intended maximum pressure, but in no case shall the range be less than $1\frac{1}{2}$ nor more than four times that pressure. These range limits do not apply to dial indicating and recording vacuum gages. Range requirements for other types of gages given in an applicable Mandatory Appendix shall be as required by that Appendix.

(b) Gage Location. When components are to be pressure/vacuum leak tested, the dial indicating gage(s) shall be connected to the component or to the component from a remote location, with the gage(s) readily visible

to the operator controlling the pressure/vacuum throughout the duration of pressurizing, evacuating, testing, and depressurizing or venting of the component. For large vessels or systems where one or more gages are specified or required, a recording type gage is recommended, and it may be substituted for one of the two or more indicating type gages.

(c) When other types of gage(s) are required by an applicable Mandatory Appendix, they may be used in conjunction with or in place of dial indicating or recording type gages.

01 T-1040 MISCELLANEOUS REQUIREMENTS

T-1041 Cleanliness

The surface areas to be tested shall be free of oil, grease, paint, or other contaminants that might mask a leak. If liquids are used to clean the component or if a hydrostatic or hydropneumatic test is performed before leak testing, the component shall be dry before leak testing.

T-1042 Openings

All openings shall be sealed using plugs, covers, sealing wax, cement, or other suitable material that can be readily and completely removed after completion of the test. Sealing materials shall be tracer gas free.

T-1043 Temperature

The minimum metal temperature for all components during a test shall be as specified in the applicable Mandatory Appendix of this Article or in the referencing Code Section for the hydrostatic, hydropneumatic, or pneumatic test of the pressure component or parts. The minimum or maximum temperature during the test shall not exceed that temperature compatible with the leak testing method or technique used.

T-1044 Pressure/Vacuum (Pressure Limits)

Unless specified in the applicable Mandatory Appendix of this Article or by the referencing Code Section, components that are to be pressure-leak tested shall not be tested at a pressure exceeding 25% of the Design Pressure.

T-1050 PROCEDURE 01

T-1051 Preliminary Leak Test

Prior to employing a sensitive leak testing method, it may be expedient to perform a preliminary test to detect and eliminate gross leaks. This shall be done in a manner that will not seal or mask leaks during the specified test.

T-1052 Test Sequence 01

It is recommended that leak testing be performed before hydrostatic or hydropneumatic testing.

T-1060 CALIBRATION

T-1061 Pressure/Vacuum Gages

(a) All dial indicating and recording type gages used shall be calibrated against a standard deadweight tester, a calibrated master gage, or a mercury column, and recalibrated at least once a year, when in use, unless specified differently by the referencing Code Section or Mandatory Appendix. All gages used shall provide results accurate to within the Manufacturer's listed accuracy and shall be recalibrated at any time that there is reason to believe they are in error.

(b) When other than dial indicating or recording type gages are required by an applicable Mandatory Appendix, they shall be calibrated as required by that Mandatory Appendix or referencing Code Section.

T-1062 Temperature Measuring Devices

When temperature measurement is required by the referencing Code Section or Mandatory Appendix, the device(s) shall be calibrated in accordance with the requirements of that Code Section or Mandatory Appendix.

T-1063 Calibration Leak Standards

T-1063.1 Permeation Type Leak Standard. This standard shall be a calibrated permeation type leak through fused glass or quartz. The standard shall have a helium leakage rate in the range of 1×10^{-6} to 1×10^{-10} std cm^3/sec. (1×10^{-7} to 1×10^{-11} Pa m^3/s) 01

T-1063.2 Capillary Type Leak Standard. This standard shall be a calibrated capillary type leak through a tube. The standard shall have a leakage rate equal to or smaller than the required test sensitivity times

the actual percent test concentration of the selected tracer gas.

T-1070 TEST

See applicable Mandatory Appendix of this Article.

T-1080 EVALUATION

T-1081 Acceptance Standards

Unless otherwise specified in the referencing Code Section, the acceptance criteria given for each method or technique of that method shall apply. The supplemental leak testing formulas for calculating leakage rates for the method or technique used are stated in the Mandatory Appendices of this Article.

T-1090 DOCUMENTATION

T-1091 Test Report

The test report shall contain, as a minimum, the following information as applicable to the method or technique:

(a) date of test;
(b) certification level and name of operator;
(c) test procedure (number) and revision number;
(d) test method or technique;
(e) test results;
(f) component identification;
(g) test instrument, standard leak, and material identification;
(h) test conditions, test pressure, tracer gas, and gas concentration;
(i) gage(s) — manufacturer, model, range, and identification number;
(j) temperature measuring device(s) and identification number(s);
(k) sketch showing method or technique setup.

T-1092 Record Retention

The test report shall be maintained in accordance with the requirements of the referencing Code Section.

ARTICLE 10
MANDATORY APPENDICES

APPENDIX I — BUBBLE TEST — DIRECT PRESSURE TECHNIQUE

I-1000 INTRODUCTION

I-1010 SCOPE

The objective of the direct pressure technique of bubble leak testing is to locate leaks in a pressurized component by the application of a solution or by immersion in liquid that will form bubbles as leakage gas passes through it.

I-1030 EQUIPMENT

I-1031 Gases

Unless otherwise specified, the test gas will normally be air; however, inert gases may be used.

NOTE: When inert gas is used, safety aspects of oxygen deficient atmosphere should be considered.

I-1032 Bubble Solution

(a) The bubble forming solution shall produce a film that does not break away from the area to be tested, and the bubbles formed shall not break rapidly due to air drying or low surface tension. Household soap or detergents are not permitted as substitutes for bubble testing solutions.

(b) The bubble forming solution shall be compatible with the temperature of the test conditions.

I-1033 Immersion Bath

(a) Water or another compatible solution shall be used for the bath.

(b) The immersion solution shall be compatible with the temperature of the test conditions.

I-1070 TEST

I-1071 Soak Time

Prior to examination the test pressure shall be held for a minimum of 15 min.

I-1072 Surface Temperature

As a standard technique, the temperature of the surface of the part to be examined shall not be below 40°F (4°C) nor above 125°F (52°C) throughout the examination. Local heating or cooling is permitted provided temperatures remain within the range of 40°F (4°C) to 125°F (52°C) during examination. Where it is impractical to comply with the foregoing temperature limitations, other temperatures may be used provided that the procedure is demonstrated.

I-1073 Application of Solution

The bubble forming solution shall be applied to the surface to be tested by flowing, spraying, or brushing the solution over the examination area. The number of bubbles produced in the solution by application should be minimized to reduce the problem of masking bubbles caused by leakage.

I-1074 Immersion in Bath

The area of interest shall be placed below the surface of the bath in an easily observable position.

I-1075 Lighting and Visual Aids

When performing the test, the requirements of Article 9, T-952 and T-953 shall apply.

I-1076 Indication of Leakage

The presence of continuous bubble growth on the surface of the material indicates leakage through an orifice passage(s) in the region under examination.

I-1077 Post-Test Cleaning

After testing, surface cleaning may be required for product serviceability.

01 I-1080 EVALUATION

I-1081 Leakage

Unless otherwise specified by the referencing Code Section, the area under test is acceptable when no continuous bubble formation is observed.

I-1082 Repair/Retest

When leakage is observed, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

APPENDIX II — BUBBLE TEST — VACUUM BOX TECHNIQUE

II-1000 INTRODUCTION

II-1010 SCOPE

The objective of the vacuum box technique of bubble leak testing is to locate leaks in a pressure boundary that cannot be directly pressurized. This is accomplished by applying a solution to a local area of the pressure boundary surface and creating a differential pressure across that local area of the boundary causing the formation of bubbles as leakage gas passes through the solution.

II-1030 EQUIPMENT

II-1031 Bubble Solution

(a) The bubble forming solution shall produce a film that does not break away from the area to be tested, and the bubbles formed shall not break rapidly due to air drying or low surface tension. The number of bubbles contained in the solution should be minimized to reduce the problem of discriminating between existing bubbles and those caused by leakage.

(b) Soaps or detergents designed specifically for cleaning shall not be used for the bubble forming solution.

(c) The bubble forming solution shall be compatible with the temperature conditions of the test.

II-1032 Vacuum Box

The vacuum box used shall be of convenient size [e.g., 6 in. (152 mm) wide by 30 in. (762 mm) long] and contain a window in the side opposite the open bottom. The open bottom edge shall be equipped with a suitable gasket to form a seal against the test surface. Suitable connections, valves, lighting, and gage shall be provided. The gage shall have a range of 0 psi (0 kPa) to 15 psi (103 kPa), or equivalent pressure units such as 0 in. Hg to 30 in. Hg. The gage range limit requirements of T-1031(a) do not apply.

II-1033 Vacuum Source

The required vacuum can be developed in the box by any convenient method (e.g., air ejector, vacuum pump, or motor intake manifold). The gage shall register a partial vacuum of at least 2 psi (4.1 in. Hg) (13.8 kPa) below atmospheric pressure or the partial vacuum required by the referencing Code Section.

II-1070 TEST

II-1071 Surface Temperature

As a standard technique, the temperature of the surface of the part to be examined shall not be below 40°F (4°C) nor above 125°F (52°C) throughout the examination. Local heating or cooling is permitted provided temperatures remain in the range of 40°F (4°C) to 125°F (52°C) during the examination. Where it is impractical to comply with the foregoing temperature limitations, other temperatures may be used provided that the procedure is demonstrated.

II-1072 Application of Solution

The bubble forming solution shall be applied to the surface to be tested by flowing, spraying, or brushing the solution over the examination area before placement of the vacuum box.

II-1073 Vacuum Box Placement

The vacuum box shall be placed over the solution coated section of the test surface and the box evacuated to the required partial vacuum.

II-1074 Pressure (Vacuum) Retention

The required partial vacuum (differential pressure) shall be maintained for at least 10 sec examination time.

II-1075 Vacuum Box Overlap

An overlap of 2 in. (51 mm) minimum for adjacent placement of the vacuum box shall be used for each subsequent examination.

II-1076 Lighting and Visual Aids

When performing the test, the requirements of Article 9, T-952 and T-953 shall apply.

II-1077 Indication of Leakage

The presence of continuous bubble growth on the surface of the material or weld seam indicates leakage through an orifice passage(s) in the region under examination.

II-1078 Post-Test Cleaning

After testing, cleaning may be required for product serviceability.

01 II-1080 EVALUATION

II-1081 Leakage

Unless otherwise specified by the referencing Code Section, the area under test is acceptable when no continuous bubble formation is observed.

II-1082 Repair/Retest

When leakage is observed, the location of the leak(s) shall be marked. The vacuum box shall then be vented and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

APPENDIX III — HALOGEN DIODE DETECTOR PROBE TEST

III-1000 INTRODUCTION

The more sophisticated electronic halogen leak detectors have very high sensitivity. These instruments make possible the detection of halogen gas flow from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures.

III-1010 SCOPE

The halogen detector probe test method is a semiquantitative method used to detect and locate leaks, and shall not be considered quantitative.

III-1011 Alkali-Ion Diode (Heated Anode) Halogen Leak Detectors

The alkali-ion diode halogen detector probe instrument uses the principle of a heated platinum element (anode) and an ion collector plate (cathode), where halogen vapor is ionized by the anode, and the ions are collected by the cathode. A current proportional to the rate of ion formation is indicated on a meter.

III-1012 Electron Capture Halogen Leak Detectors

The electron capture halogen detector probe instrument uses the principle of the affinity of certain molecular compounds for low energy free electrons usually produced by ionization of gas flow through an element with a weak radioactive tritium source. When the gas flow contains halides, electron capture occurs causing a reduction in the concentration of halogen ions present as indicated on a meter. Non-electron capturing nitrogen or argon is used as background gas.

III-1030 EQUIPMENT

III-1031 Tracer Gas

Gases that may be used are shown in Table III-1031.

III-1031.1 For Alkali-Ion Diode. Halogen leak detectors, select a tracer gas from Table III-1031 that will produce the necessary test sensitivity.

III-1031.2 For Electron Capture. Halogen leak detectors, sulfur hexafluoride, SF_6, is the recommended tracer gas.

III-1032 Instrument

An electronic leak detector as described in III-1011 or III-1012 shall be used. Leakage shall be indicated by one or more of the following signaling devices.

TABLE III-1031
TRACER GASES

Commercial Designation	Chemical Designation	Chemical Symbol
Refrigerant-11	Trichloromonofluoromethane	CCl_3F
Refrigerant-12	Dichlorodifluoromethane	CCl_2F_2
Refrigerant-21	Dichloromonofluoromethane	$CHCl_2F$
Refrigerant-22	Chlorodifluoromethane	$CHClF_2$
Refrigerant-114	Dichlorotetrafluoroethane	$C_2Cl_2F_4$
Refrigerant-134a	Tetrafluoroethane	$C_2H_2F_4$
Methylene Chloride	Dichloromethane	CH_2Cl_2
Sulfur Hexafluoride	Sulfur Hexafluoride	SF_6

(a) Meter — a meter on the test instrument, or a probe, or both.

(b) Audio Devices — a speaker or set of headphones that emits audible indications.

(c) Indicator Light — a visible indicator light.

III-1033 Capillary Calibration Leak Standard

A capillary type leak standard per T-1063.2 using 100% tracer gas as selected per III-1031.

III-1060 CALIBRATION

01 ### III-1061 Standard Leak Size

The maximum leakage rate Q for the leak standard described in III-1033 containing 100% tracer concentration for use in III-1063 shall be calculated as follows:

$$Q = Q_s \frac{\%TG}{100}$$

where Q_s is 1×10^{-4} std cm^3/s (1×10^{-5} Pa m^3/s), unless specified otherwise by the referencing Code Section, and %TG is the concentration of the tracer gas (in %) that is to be used for the test (See III-1072).

01 ### III-1062 Warm Up

The detector shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the leak standard.

01 ### III-1063 Scanning Rate

The instrument shall be calibrated by passing the probe tip across the orifice of the leak standard in III-1061. The probe tip shall be kept within ⅛ in. (3.2 mm) of the orifice of the leak standard. The scanning rate shall not exceed that which can detect leakage rate Q from the leak standard. The meter deflection shall be noted or the audible alarm or indicator light set for this scanning rate.

III-1064 Detection Time 01

The time required to detect leakage from the leak standard is the detection time and it should be observed during system calibration. It is usually desirable to keep this time as short as possible to reduce the time required to pinpoint detected leakage.

III-1065 Frequency and Sensitivity 01

Unless otherwise specified by the referencing Code Section, the sensitivity of the detector shall be determined before and after testing and at intervals of not more than 4 hr during testing. During any calibration check, if the meter deflection, audible alarm, or indicator light indicates that the detector cannot detect leakage from the leak standard of III-1061, the instrument shall be recalibrated and areas tested after the last satisfactory calibration check shall be retested.

III-1070 TEST

III-1071 Location of Test

(a) The test area shall be free of contaminants that could interfere with the test or give erroneous results.

(b) The component to be tested shall, if possible, be protected from drafts or located in an area where drafts will not reduce the required sensitivity of the test.

III-1072 Concentration of Tracer Gas

The concentration of the tracer gas shall be at least 10% by volume at the test pressure, unless otherwise specified by the referencing Code Section.

III-1073 Soak Time

Prior to examination, the test pressure shall be held a minimum of 30 min. When demonstrated, the minimum allowable soak time may be less than that specified above due to the immediate dispersion of the halogen gas when:

(a) a special temporary device (such as a leech box) is used on open components to test short segments;

(b) components are partially evacuated prior to initial pressurization with halogen gas.

III-1074 Scanning Distance

After the required soak time per III-1073, the detector probe tip shall be passed over the test surface. The probe tip shall be kept within $\frac{1}{8}$ in. (3.2 mm) of the test surface during scanning. If a shorter distance is used during calibration, then that distance shall not be exceeded during the examination scanning.

III-1075 Scanning Rate

The maximum scanning rate shall be as determined in III-1063.

III-1076 Scanning Direction

The examination scan should commence in the uppermost portion of the system being leak tested while progressively scanning downward.

01 III-1077 Leakage Detection

Leakage shall be indicated and detected according to III-1032.

III-1078 Application

The following are two examples of applications that may be used (note that other types of applications may be used).

III-1078.1 Tube Examination. To detect leakage through the tube walls when testing a tubular heat exchanger, the detector probe tip should be inserted into each tube end and held for the time period established by demonstration. The examination scan should commence in the uppermost portion of the tubesheet tube rows while progressively scanning downward.

01 **III-1078.2 Tube-to-Tubesheet Joint Examination.** Tube-to-tubesheet joints may be tested by the encapsulator method. The encapsulator may be a funnel type with the small end attached to the probe tip end and the large end placed over the tube-to-tubesheet joint. If the encapsulator is used, the detection time is determined by placing the encapsulator over the orifice on the leak standard and noting the time required for an indicated instrument response.

III-1080 EVALUATION 01

III-1081 Leakage

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the allowable rate of 1×10^{-4} std cm^3/s (1×10^{-5} Pa m^3/s).

III-1082 Repair/Retest

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

APPENDIX IV — HELIUM MASS SPECTROMETER TEST — DETECTOR PROBE TECHNIQUE

IV-1000 INTRODUCTION

IV-1010 SCOPE

This technique describes the use of the helium mass spectrometer to detect minute traces of helium gas in pressurized components. The high sensitivity of this leak detector makes possible the detection of helium gas flow from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures, or the determination of the presence of helium in any gaseous mixture. The detector probe is a semiquantitative technique used to detect and locate leaks, and shall not be considered quantitative.

IV-1030 EQUIPMENT

IV-1031 Instrument

A helium mass spectrometer leak detector capable of sensing and measuring minute traces of helium shall be used. Leakage shall be indicated by one or more of the following signaling devices.

(a) *Meter* — a meter on, or attached to, the test instrument.

(b) *Audio Devices* — a speaker or set of headphones that emits audible indications.

(c) *Indicator Light* — a visible indicator light.

IV-1032 Auxiliary Equipment

(a) Transformer. A constant voltage transformer shall be used in conjunction with the instrument when line voltage is subject to variations.

(b) Detector Probe. All areas to be examined shall be scanned for leaks using a detector probe (sniffer) connected to the instrument through flexible tubing or a hose. To reduce instrument response and clean up time, the tubing or hose length shall be less than 15 ft (4.6 m), unless the test setup is specifically designed to attain the reduced response and clean up time for longer tubing or hose lengths.

IV-1033 Calibration Leak Standards

Calibration leak standards may be either a permeation or capillary type standard per T-1063.1 and T-1063.2. The type of leak standard used shall be established by the instrument or system sensitivity requirement, or as specified by the referencing Code Section.

IV-1060 CALIBRATION

IV-1061 Instrument Calibration

IV-1061.1 Warm Up. The instrument shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the calibrated leak standard.

01 **IV-1061.2 Calibration.** Calibrate the helium mass spectrometer per the instruments manufacturer's operation and maintenance manual, using a permeation type leak standard as stated in T-1063.1 to establish that the instrument is at optimum or adequate sensitivity. The instrument shall have a sensitivity of at least 1×10^{-9} std cm^3/s (1×10^{-10} Pa m^3/s) for helium.

IV-1062 System Calibration

01 **IV-1062.1 Standard Leak Size.** The maximum leakage rate Q for the leak standard described in IV-1033, containing 100% helium concentration for use in IV-1062.2, shall be calculated as follows:

$$Q = Q_s \frac{\%TG}{100}$$

where Q_s is 1×10^{-4} std cm^3/s (1×10^{-5} Pa m^3/s), unless specified otherwise by the referencing Code Section, and *%TG* is the concentration of the tracer gas (in %) that is to be used for the test (See IV-1072).

IV-1062.2 Scanning Rate. After connecting the detector probe to the instrument, the system shall be calibrated by passing the detector probe tip across the orifice of the leak standard in IV-1062.1. The probe tip shall be kept within $\frac{1}{8}$ in. (3.2 mm) of the orifice of the leak standard. The scanning rate shall not exceed that which can detect leakage rate Q from the leak standard. The meter deflection shall be noted the audible alarm or indicator light set for this scanning rate. 01

IV-1062.3 Detection Time. The time required to detect leakage from the leak standard is the detection time, and it should be observed during system calibration. It is usually desirable to keep this time as short as possible to reduce the time required to pinpoint detected leakage. 01

IV-1062.4 Frequency and Sensitivity. Unless otherwise specified by the referencing Code Section, the system sensitivity shall be determined before and after testing and at intervals of not more than 4 hr during the test. During any calibration check, if the meter deflection, audible alarm, or visible light indicates that the system cannot detect leakage per IV-1062.2, the system, and if necessary, the instrument, shall be recalibrated and all areas tested after the last satisfactory calibration check shall be retested. 01

IV-1070 TEST

IV-1071 Location of Test

The component to be tested shall, if possible, be protected from drafts or located in an area where drafts will not reduce the required sensitivity of the test.

IV-1072 Concentration of Tracer Gas

The concentration of the helium tracer gas shall be at least 10% by volume at the test pressure, unless otherwise specified by the referencing Code Section.

IV-1073 Soak Time 01

Prior to testing, the test pressure shall be held a minimum of 30 min. The minimum allowable soak time may be less than that specified above due to the immediate dispersion of the helium gas when:

(a) a special temporary device (such as a leech box) is used on open components to test short segments;

(b) components are partially evacuated prior to initial pressurization with helium gas.

IV-1074 Scanning Distance

After the required soak time per IV-1073, the detector probe tip shall be passed over the test surface. The probe tip shall be kept within $\frac{1}{8}$ in. (3.2 mm) of the test surface during scanning. If a shorter distance is used during system calibration, then that distance shall not be exceeded during test scanning.

IV-1075 Scanning Rate

The maximum scanning rate shall be as determined in IV-1062.2.

IV-1076 Scanning Direction

The examination scan should commence in the lowermost portion of the system being tested while progressively scanning upward.

01 IV-1077 Leakage Detection

Leakage shall be indicated and detected according to IV-1031.

IV-1078 Application

The following are two examples of applications that may be used (note that other types of applications may be used).

IV-1078.1 Tube Examination. To detect leakage through the tube walls when testing a tubular heat exchanger, the detector probe tip should be inserted into each tube end and held for the time period established by demonstration. The examination scan should commence in the lowermost portion of the tubesheet tube rows while progressively scanning upward.

01 **IV-1078.2 Tube-to-Tubesheet Joint Examination.** Tube-to-tubesheet joints may be tested by the encapsulator method. The encapsulator may be a funnel type with the small end attached to the probe tip end and the large end placed over the tube-to-tubesheet joint. If the encapsulator is used, the detection time is determined by placing the encapsulator over the orifice on the leak standard and noting the time required for an indicated instrument response.

IV-1080 EVALUATION 01

IV-1081 Leakage

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the allowable rate of 1×10^{-4} std cm^3/s (1×10^{-5} Pa m^3/s).

IV-1082 Repair/Retest

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

APPENDIX V — HELIUM MASS SPECTROMETER TEST — TRACER PROBE TECHNIQUE 01

V-1010 SCOPE 01

This technique describes the use of the helium mass spectrometer to detect minute traces of helium gas in evacuated components.

The high sensitivity of this leak detector, when tracer probe testing, makes possible the detection and location of helium gas flow from the higher pressure side of very small openings through the evacuated envelope or barrier separating the two regions at different pressures. This is a semiquantitative technique and shall not be considered quantitative.

V-1030 EQUIPMENT

V-1031 Instrument 01

A helium mass spectrometer leak detector capable of sensing and measuring minute traces of helium shall be used. Leakage shall be indicated by one or more of the following signaling devices.

(a) Meter — a meter on or attached to the test instrument.

(b) Audio Devices — a speaker or set of headphones that emits audible indications.

(c) Indicator Light — a visible indicator light.

01 **V-1032 Auxiliary Equipment**

(a) Transformer. A constant voltage transformer shall be used in conjunction with the instrument when line voltage is subject to variations.

(b) Auxiliary Pump System. When the size of the test system necessitates the use of an auxiliary vacuum pump system, the ultimate absolute pressure and pump speed capability of that system shall be sufficient to attain required test sensitivity and response time.

(c) Manifold. A system of pipes and valves with proper connections for the instrument gages, auxiliary pump, calibration leak standard, and test component.

(d) Tracer Probe. Tubing connected to a source of 100% helium with a valved fine opening at the other end for directing a fine stream of helium gas.

(e) Vacuum Gage(s). The range of vacuum gage(s) capable of measuring the absolute pressure at which the evacuated system is being tested. The gage(s) for large systems shall be located on the system as far as possible from the inlet to the pump system.

01 **V-1033 Calibration Leak Standard**

A capillary type leak standard per T-1063.2 with a maximum helium leakage rate of 1×10^{-5} std cm^3/s (1×10^{-6} Pa m^3/s) shall be used unless otherwise specified by the referencing Code Section.

V-1060 CALIBRATION

V-1061 Instrument Calibration

V-1061.1 Warm Up. The instrument shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the calibration leak standard.

01 **V-1061.2 Calibration.** Calibrate the helium mass spectrometer per the instruments manufacturer's operation and maintenance manual, using a permeation type leak standard as stated in T-1063.1 to establish that the instrument is at optimum or adequate sensitivity. The instrument shall have a sensitivity of at least 1×10^{-9} std cm^3/s (1×10^{-10} Pa m^3/s) for helium.

V-1062 System Calibration

01 **V-1062.1 Standard Leak Size.** The calibrated leak standard, as stated in V-1033, shall be attached to the component as far as possible from the instrument connection to the component. The leak standard shall remain open during system calibration.

V-1062.2 Scanning Rate. With the component evacuated to an absolute pressure sufficient for connection of the helium mass spectrometer to the system, the system shall be calibrated for the test by passing the tracer probe tip across the orifice of the leak standard. The probe tip shall be kept within ¼ in. (6 mm) of the orifice of the leak standard. For a known flow rate from the tracer probe of 100% helium, the scanning rate shall not exceed that which can detect leakage through the calibration leak standard into the test system. 01

V-1062.3 Detection Time. The time required to detect leakage from the leak standard is the detection time, and it should be observed during system calibration. It is desirable to keep this time as short as possible to reduce the time required to pinpoint detected leakage. 01

V-1062.4 Frequency and Sensitivity. Unless otherwise specified by the referencing Code Section, the system sensitivity shall be determined before and after testing and at intervals of not more than 4 hr during testing. During any calibration check, if the meter deflection, audible alarm, or visible light indicates that the system cannot detect leakage per V-1062.2, the system, and if necessary, the instrument, shall be recalibrated and all areas tested after the last satisfactory calibration check shall be retested. 01

V-1062.5 Hood Technique. A calibrated leak *CL* standard as per T-1063.1 with 100% helium shall be attached, where feasible, to the component as far as possible from the instrument connection to the component. The calibrated leak standard shall remain open during system calibration until the response time has been determined. 01

(a) Evacuation. With the component evacuated to an absolute pressure sufficient for connection of the helium mass spectrometer to the system, the calibrated leak standard shall be opened to the system. The calibrated leak standard shall remain open until the instrument signal becomes stable, and the response time has been determined.

(b) Response Time. The time is recorded when the calibrated leak standard is opened to the component and when the increase in output signal becomes stable. The elapsed time between the two readings is the response time. The stable instrument reading shall be noted and recorded as M_1 in divisions.

(c) Background Reading.[1] Background M_2 in divisions is established after determining response time. The calibration leak standard is closed to the system

[1] System background noise. For definition of symbols, see Nonmandatory Appendix A.

and the instrument reading shall be recorded when it becomes stable.

(d) Preliminary Calibration. The preliminary system sensitivity shall be calculated as follows:

$$S_1 = \frac{CL}{M_1 - M_2} = \text{std cm}^3/\text{sec}/\text{div}$$

The calibration shall be repeated when there is any change in the leak detector setup (e.g., a change in the portion of helium bypassed to the auxiliary pump, if used) or any change in the calibrated leak. The calibrated leak standard shall be isolated from the system upon completing the preliminary system sensitivity calibration.

(e) Final Calibration. Upon completing the test of the system, and with the component still under the hood, the instrument output reading M_3 shall be determined with the calibrated leak closed. Again, the calibrated leak shall be opened into the system being tested. The increase in instrument output M_4 shall be used in calculating the final system sensitivity as follows:

$$S_2 = \frac{CL}{M_4 - M_3} \text{ std cm}^3/\text{sec}/\text{div}$$

If the final system sensitivity S_2 has decreased below the initial system sensitivity S_1 by more than 35%, the instrument shall be cleaned and/or repaired, recalibrated and the component or system retested.

(f) Measured Leakage Rate. The measured leakage rate of the component shall be determined as follows:

$$Q_1 = S_2(M_3 - M_2) \text{ std cm}^3/\text{sec}$$

(g) Actual Leakage Rate. Calculation of actual leakage rate (corrected for tracer gas concentration used):

$$Q_2 = \frac{Q_1 \times 100}{\% \text{ He}} \text{ std cm}^3/\text{sec}$$

V-1070 TEST

01 V-1071 Scanning Rate

The maximum scanning rate shall be as determined in V-1062.2.

V-1072 Scanning Direction 01

The examination scan should commence in the uppermost portion of the system being tested while progressively scanning downward.

V-1073 Scanning Distance 01

The tracer probe tip shall be kept within $\frac{1}{4}$ in. (6 mm) of the test surface during scanning. If a shorter distance is used during system calibration, then that distance shall not be exceeded during the examination scanning.

V-1074 Leakage Detection 01

Leakage shall be indicated and detected according to V-1031.

V-1075 Flow Rate 01

The minimum flow rate shall be as set in V-1062.2.

V-1080 EVALUATION 01

V-1081 Leakage

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the allowable rate of 1×10^{-5} std cm^3/s (1×10^{-6} Pa m^3/s).

V-1082 Repair/Retest

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be vented, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

APPENDIX VI — PRESSURE CHANGE TEST

VI-1010 SCOPE

This test method describes the techniques for determining the leakage rate of the boundaries of a closed component or system at a specific pressure or vacuum. Pressure hold, absolute pressure, maintenance of pressure, pressure loss, pressure decay, pressure rise, and vacuum retention are examples of techniques that may be used whenever pressure change testing is specified

as a means of determining leakage rates. The tests specify a maximum allowable change in either pressure per unit of time, percentage volume, or mass change per unit of time.

VI-1020 GENERAL

Each of the tests shall be performed by either pneumatic pressurization or evacuation of a closed component or system to a specific pressure or vacuum. Temperature, pressure, or vacuum are systematically recorded for a specified period of time. Analysis of data determines the component or system acceptability with respect to leakage rate or pressure change per unit of time.

VI-1030 EQUIPMENT

VI-1031 Pressure Measuring Instruments

(a) Gage Range. Dial indicating and recording type gages shall meet the requirements of T-1031(a). Liquid manometers or quartz Bourdon tube gages may be used over their entire range.

(b) Gage Location. The location of the gage(s) shall be that stated in T-1031(b).

(c) Types of Gages. Regular or absolute gages may be used in pressure change testing. When greater accuracy is required, quartz Bourdon tube gages or liquid manometers may be used. The gage(s) used shall have an accuracy, resolution, and repeatability compatible with the acceptance criteria.

VI-1032 Temperature Measuring Instruments

Dry bulb or dew point temperature measuring instruments, when used, shall have accuracy, repeatability, and resolution compatible with the leakage rate acceptance criteria.

VI-1060 CALIBRATION

VI-1061 Pressure Measuring Instruments

All dial indicating, recording, and quartz Bourdon tube gages shall be calibrated per T-1061(b). The scale of liquid manometers shall be calibrated against standards that have known relationships to national standards, where such standards exist.

VI-1062 Temperature Measuring Instruments

Calibration for dry bulb and dew point temperature measuring instruments shall be against standards that have known relationships to national standards, where such standards exist.

VI-1070 TEST

VI-1071 Pressure Application

Components that are to be tested above atmospheric pressure shall be pressurized per T-1044.

VI-1072 Vacuum Application

Components that are to be tested under vacuum shall be evacuated to at least 2 psi (4.1 in. Hg) (13.8 kPa) below atmospheric pressure or as required by the referencing Code Section.

VI-1073 Test Duration

The test pressure (or vacuum) shall be held for the duration specified by the referencing Code Section or, if not specified, it shall be sufficient to establish the leakage rate of the component system within the accuracy or confidence limits required by the referencing Code Section. For very small components or systems, a test duration in terms of minutes may be sufficient. For large components or systems, where temperature and water vapor corrections are necessary, a test duration in terms of many hours may be required.

VI-1074 Small Pressurized Systems

For temperature stabilization of very small pressurized systems, such as gasket interspaces, where only system (metal) temperature can be measured, at least 15 min shall elapse after completion of pressurization and before starting the test.

VI-1075 Large Pressurized Systems

For temperature stabilization of large pressurized systems where the internal gas temperature is measured after completion of pressurization, it shall be determined that the temperature of the internal gas has stabilized before starting the test.

VI-1076 Start of Test

At the start of the test, initial temperature and pressure (or vacuum) readings shall be taken and thereafter at regular intervals, not to exceed 60 min, until the end of the specified test duration.

VI-1077 Essential Variables

(a) When it is required to compensate for barometric pressure variations, measurement of the test pressure shall be made with either an absolute pressure gage or a regular pressure gage and a barometer.

(b) When it is required by the referencing Code Section, or when the water vapor pressure variation can significantly affect the test results, the internal dew point temperature or relative humidity shall be measured.

VI-1080 EVALUATION

VI-1081 Acceptable Test

When the pressure change or leakage rate is equal to or less than that specified by the referencing Code Section, the test is acceptable.

VI-1082 Rejectable Test

When the pressure change or leakage rate exceeds that specified by the referencing Code Section, the results of the test are unsatisfactory. Leak(s) may be located by other methods described in the Mandatory Appendices. After the cause of the excessive pressure change or leakage rate has been determined and repaired in accordance with the referencing Code Section, the original test shall be repeated.

NOTE: For more information regarding this method of testing refer to the following:

(a) 10 CFR 50, Appendix J, *Primary Containment Leakage Testing for Water Cooled Power Reactors.*

(b) ANSI/ANS 56.8-1981, *American National Standard Containment System Leakage Testing Requirements,* published by the American Nuclear Society.

APPENDIX VII — GLOSSARY OF TERMS FOR LEAK TESTING

VII-1010 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms which appear in Article 10, Leak Testing.

VII-1020 GENERAL 01

(a) ASTM E 1316, Standard Terminology for Nondestructive Examinations, has been adopted by the Committee as SE-1316.

(b) SE-1316 Section 8 provides the definitions of terms listed in (e).

(c) For general terms such as *Discontinuity, Evaluation, Flaw, Indication, Inspection,* etc., refer to Article 1, Mandatory Appendix I.

(d) The following SE-1316 terms are used in conjunction with this Article: *absolute pressure; background signal; gage pressure; gas; halogen; halogen leak detector; hood test; leak; leakage rate; leak testing; mass spectrometer; mass spectrometer leak detector; sampling probe; standard leak; tracer gas; vacuum.*

(e) The following Code terms, which are in addition to SE-1316, and are Code specific, are used in conjunction with this Article.

background reading — see *background signal* in (d)

calibration leak standard — see *standard leak* in (d)

detector probe — see *sampling probe* in (d)

dew point temperature — that temperature at which the gas in a system would be capable of holding no more water vapor and condensation in the form of dew would occur

dry bulb temperature — the ambient temperature of the gas in a system

halogen diode detector — see *halogen leak detector* in (d)

helium mass spectrometer — see *mass spectrometer* and *mass spectrometer leak detector* in (d)

hood technique — see *hood test* in (d)

immersion bath — a low surface tension liquid into which a gas containing enclosure is submerged to detect leakage which forms at the site or sites of a leak or leaks

immersion solution — see *immersion bath*

inert gas — a gas that resists combining with other substances. Examples are helium, neon, and argon.

instrument calibration — introduction of a known size standard leak into an isolated leak detector for the purpose of determining the smallest size leakage rate of a particular gas at a specific pressure and temperature that the leak detector is capable of indicating for a particular division on the leak indicator scale

leakage — the fluid, either liquid or gas, flowing through a leak and expressed in units of mass flow; i.e., pressure and volume per time

leak standard — see *standard leak* in (d)

quartz Bourdon tube gage — this high accuracy gage is a servonulling differential pressure measuring electronic instrument. The pressure transducing element is a one piece fused quartz Bourdon element.

regular pressure — see *gage pressure* in (d)

sensitivity — the size of the smallest leakage rate that can be unambiguously detected by the leak testing instrument, method, or technique being used

soak time — the elapsed time between when the desired differential pressure is attained on a system and the time when the test technique is performed to detect leakage or measure leakage rate

standard dead weight tester — a device for hydraulically balancing the pressure on a known high accuracy weight against the reading on a pressure gage for the purpose of calibrating the gage

system calibration — introduction of a known size standard leak into a test system with a leak detector for the purpose of determining the smallest size leakage rate of a particular gas at a specific pressure and temperature that the leak detector as part of the test system is capable of indicating for a particular division on the leak indicator scale

thermal conductivity detector — a leak detector that responds to differences in the thermal conductivity of a sampled gas and the gas used to zero it (i.e., background atmosphere)

vacuum box — a device used to obtain a pressure differential across a weld that cannot be directly pressurized. It contains a large viewing window, special easy seating and sealing gasket, gage, and a valved connection for an air ejector, vacuum pump, or intake manifold

water vapor — gaseous form of water in a system

APPENDIX VIII — THERMAL CONDUCTIVITY DETECTOR PROBE TEST

VIII-1000 INTRODUCTION

These instruments make possible the detection of a tracer gas flow from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures.

VIII-1010 SCOPE

The thermal conductivity detector probe test method is a semiquantitative method used to detect and locate leaks, and shall not be considered quantitative.

VIII-1011 Thermal Conductivity Leak Detectors

The thermal conductivity detector probe instrument uses the principle that the thermal conductivity of a gas or gas mixture changes with any change in the concentration(s) of the gas or gas mixture (i.e., the introduction of a tracer gas in the area of a leak).

TABLE VIII-1031
TRACER GASES

Designation	Chemical Designation	Chemical Symbol
...	Helium	He
...	Argon	Ar
...	Carbon Dioxide	CO_2
Refrigerant-11	Trichloromonofluoromethane	CCl_3F
Refrigerant-12	Dichlorodifluoromethane	CCl_2F_2
Refrigerant-21	Dichloromonofluoromethane	$CHCl_2F$
Refrigerant-22	Chlorodifluoromethane	$CHClF_2$
Refrigerant-114	Dichlorotetrafluoroethane	$C_2Cl_2F_4$
Refrigerant-134a	Tetrafluoroethane	$C_2H_2F_4$
Methylene Chloride	Dichloromethane	CH_2Cl_2
Sulfur Hexafluoride	Sulfur Hexafluoride	SF_6

VIII-1030 EQUIPMENT

VIII-1031 Tracer Gas

In principle, any gas having a thermal conductivity different from air can be used as a tracer gas. The sensitivity achievable depends on the relative differences of the thermal conductivity of the gases [i.e., background air (air used to zero the instrument) and the sampled air (air containing the tracer gas) in the area of a leak]. Table VIII-1031 lists some of the typical tracer gases used. The tracer gas to be used shall be selected based on the required test sensitivity.

VIII-1032 Instrument

An electronic leak detector as described in VIII-1011 shall be used. Leakage shall be indicated by one or more of the following signaling devices:

(a) Meter. A meter on the test instrument, or a probe, or both.

(b) Audio Devices. A speaker or sets of headphones that emit(s) audible indications.

(c) Indicator Light. A visible indicator light.

VIII-1033 Capillary Calibration Leak Standard

A capillary type leak standard per T-1063.2 using 100% tracer gas as selected per VIII-1031.

VIII-1060 CALIBRATION

01 ### VIII-1061 Standard Leak Size

The maximum leakage rate Q for the leak standard described in VIII-1033 containing 100% tracer concentration for use in VIII-1063 shall be calculated as follows:

$$Q = Q_s \frac{\%\ TG}{100}$$

where Q_s [in std cm^3/s (Pa m^3/s)] is the required test sensitivity and $\%TG$ is the concentration of the tracer gas (in %) that is to be used for the test. See VIII-1072.

01 ### VIII-1062 Warm-up

The detector shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the leak standard.

01 ### VIII-1063 Scanning Rate

The detector shall be calibrated by passing the probe tip across the orifice of the leak standard in VIII-1061. The probe tip shall be kept within $\frac{1}{2}$ in. (13 mm) of the orifice of the leak standard. The scanning rate shall not exceed that which can detect leakage rate Q from the leak standard. The meter deflection shall be noted or the audible alarm or indicator light set for this scanning rate.

01 ### VIII-1064 Detection Time

The time required to detect leakage from the leak standard is the detection time and it should be observed during system calibration. It is usually desirable to keep this time as short as possible to reduce the time required to pinpoint detected leakage.

01 ### VIII-1065 Frequency and Sensitivity

Unless otherwise specified by the referencing Code Section, the sensitivity of the detector shall be determined before and after testing and at intervals of not more than 4 hr during testing. During any calibration check, if the meter deflection, audible alarm, or indicator light indicate that the detector cannot detect leakage per VIII-1063, the instrument shall be recalibrated and areas tested after the last satisfactory calibration check shall be retested.

VIII-1070 TEST

VIII-1071 Location of Test

(a) The test area shall be free of contaminants that could interfere with the test or give erroneous results.

(b) The component to be tested shall, if possible, be protected from drafts or located in an area where drafts will not reduce the required sensitivity of the test.

VIII-1072 Concentration of Tracer Gas

The concentration of the tracer gas shall be at least 10% by volume at the test pressure, unless otherwise specified by the referencing Code Section.

VIII-1073 Soak Times

Prior to examination, the test pressure shall be held a minimum of 30 min. When demonstrated, the minimum allowable soak time may be less than that specified above due to the immediate dispersion of the tracer gas when:

(a) a special temporary device (such as a leech box) is used on open components to test short segments;

(b) components are partially evacuated prior to initial pressurization with tracer gas.

VIII-1074 Scanning Distance

After the required soak time per VIII-1073, the detector probe tip shall be passed over the test surface. The probe tip shall be kept within $\frac{1}{2}$ in. (13 mm) of the test surface during scanning. If a shorter distance is used during calibration, then that distance shall not be exceeded during the examination scanning.

VIII-1075 Scanning Rate

The maximum scanning rate shall be as determined in VIII-1063.

VIII-1076 Scanning Direction

For tracer gases that are lighter than air, the examination scan should commence in the lowermost portion of the system being tested while progressively scanning upward. For tracer gases that are heavier than air, the examination scan should commence in the uppermost portion of the system being tested while progressively scanning downward.

01 **VIII-1077 Leakage Detection**

Leakage shall be indicated and detected according to VIII-1032.

VIII-1078 Application

The following are two examples of applications that may be used (note that other types of applications may be used).

VIII-1078.1 Tube Examination. To detect leakage through the tube walls when testing a tubular heat exchanger, the detector probe tip should be inserted into each tube and held for the time period established by demonstration.

01 **VIII-1078.2 Tube-to-Tubesheet Joint Examination.** Tube-to-tubesheet joints may be tested by the encapsulator method. The encapsulator may be a funnel type with the small end attached to the probe tip end and the large end placed over the tube-to-tubesheet joint. If the encapsulator is used, the detection time is determined by placing the encapsulator over the orifice on the leak standard and noting the time required for an indicated instrument response.

VIII-1080 EVALUATION 01

VIII-1081 Leakage

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the maximum leakage rate Q, determined per VIII-1061.

VIII-1082 Repair/Retest

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

01

ARTICLE 10 — APPENDIX IX HELIUM MASS SPECTROMETER TEST — HOOD TECHNIQUE

IX-1010 SCOPE

This technique describes the use of the helium mass spectrometer to respectively detect and measure minute traces of helium gas in evacuated components.

The high sensitivity of this leak detector, when hood testing, makes possible the detection and measurement of total helium gas flow from the higher pressure side of all hooded, very small openings through the evacuated envelope or barrier that separates the two regions at different pressures. This is a quantitative measurement technique.

IX-1030 EQUIPMENT

IX-1031 Instrument

A helium mass spectrometer leak detector capable of sensing and measuring minute traces of helium shall be used. Leakage shall be indicated by a meter on or attached to the test instrument.

IX-1032 Auxiliary Equipment

(a) Transformer. A constant voltage transformer shall be used in conjunction with the instrument when line voltage is subject to variations.

(b) Auxiliary Pump System. When the size of the test system necessitates the use of an auxiliary vacuum pump system, the ultimate absolute pressure and pump speed capability of that system shall be sufficient to attain required test sensitivity and response time.

(c) Manifold. A system of pipes and valves with proper connections for the instrument gages, auxiliary pump, calibration leak standard, and test component.

(d) Hood. Any suitable envelope or container, such as a plastic bag, with a through aperture for the manifold.

(e) Vacuum Gage(s). The range of vacuum gage(s) capable of measuring the absolute pressure at which the evacuated system is being tested. The gage(s) for large systems shall be located on the system as far as possible from the inlet to the pump system.

IX-1033 Calibration Leak Standard

A permeation type leak standard per T-1063.1 with a maximum helium leakage rate of 1×10^{-6} std cm^3/s (1×10^{-7} Pa m^3/s) shall be used, unless specified otherwise by the referencing Code Section.

IX-1050 TECHNIQUE

IX-1051 Permeation

When systems with long response times (i.e., low helium mass spectrometer throughput) are to be tested, helium permeation through nonmetallic seals can lead to false results. In cases like this, it is recommended, if possible, to locally hood test such seals or exclude them from the hood if the seals are not required to be tested.

IX-1052 Repetitive or Similar Tests

For repetitive tests or where the test time is known from previous similar tests, the preliminary calibration, per IX-1062.4, may be omitted.

IX-1060 CALIBRATION

IX-1061 Instrument Calibration

IX-1061.1 Warm Up. The instrument shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the leak standard.

IX-1061.2 Calibration. Calibrate the helium mass spectrometer per the instrument manufacturer's operation and maintenance manual using a permeation type

leak standard as stated in T-1063.1 to establish that the instrument is at optimum or adequate sensitivity. The instrument shall have sensitivity of at least 1 × 10^{-9} std cm^3/s (1 × 10^{-10} Pa m^3/s) for helium.

IX-1062 System Calibration

IX-1062.1 Standard Leak Size. A calibrated leak *CL* standard as per T-1063.1 with 100% helium shall be attached, where feasible, to the component as far as possible from the instrument connection to the component.

IX-1062.2 Response Time. With the component evacuated to an absolute pressure sufficient for connection of the helium mass spectrometer to the system, the system shall be calibrated by opening the leak standard to the system. The leak standard shall remain open until the instrument signal becomes stable.

The time shall be recorded when the leak standard is first opened to the component and again when the increase in output signal becomes stable. The elapsed time between the two readings is the response time. The stable instrument reading shall be noted and recorded as M_1 in divisions.

IX-1062.3 Background Reading.[1] Background M_2 in divisions is established after determining response time. The leak standard shall be closed to the system and the instrument reading shall be recorded when it becomes stable.

IX-1062.4 Preliminary Calibration. The preliminary system sensitivity shall be calculated as follows:

$$S_1 = \frac{CL}{M_1 - M_2} = \text{std cm}^3/\text{s}/\text{div (Pa m}^3/\text{s}/\text{div)}$$

The calibration shall be repeated when there is any change in the leak detector setup (e.g., a change in the portion of helium bypassed to the auxiliary pump, if used) or any change in the leak standard. The leak standard shall be isolated from the system upon completing the preliminary system sensitivity calibration.

IX-1062.5 Final Calibration. Upon completing the test of the system per IX-1071.4, and with the component still under the hood, the leak standard shall be again opened into the system being tested. The increase in instrument output shall be noted and recorded as M_4 in divisions and used in calculating the final system sensitivity as follows:

$$S_2 = \frac{CL}{M_4 - M_3} = \text{std cm}^3/\text{s}/\text{div (Pa m}^3/\text{s}/\text{div)}$$

If the final system sensitivity S_2 has decreased below the preliminary system sensitivity S_1 by more than 35%, the instrument shall be cleaned and/or repaired, recalibrated, and the component retested.

IX-1070 TEST

IX-1071 Standard Technique

IX-1071.1 Hood. For a single wall component or part, the hood (envelope) container may be made of a material such as plastic.

IX-1071.2 Filling of Hood with Tracer Gas. After completing preliminary calibration per IX-1062.4, the space between the component outer surface and the hood shall be filled with helium.

IX-1071.3 Estimating or Determining Hood Tracer Gas Concentration. The tracer gas concentration in the hood enclosure shall be determined or estimated.

IX-1071.4 Test Duration. After filling the hood with helium, the instrument output M_3 in divisions shall be noted and recorded after waiting for a test time equal to the response time determined in IX-1062.2 or, if the output signal has not become stable, until the output signal stabilizes.

IX-1071.5 System Measured Leakage Rate. After completing final calibration per IX-1062.5, the system leakage rate shall be determined as follows:

(a) For tests where no change in output signal occurs (i.e., $M_2 = M_3$), the system leakage rate shall be reported as being "below the detectable range of the system" and the item under test passes.

(b) For tests where the output signal (M_3) remains on scale, the leakage rate shall be determined as follows:

$$Q = \frac{S_2 (M_3 - M_2) \times 100}{\%\text{TG}} \text{ std cm}^3/\text{s (Pa m}^3/\text{s)}$$

where %TG is the concentration of the tracer gas (in %) in the hood. See IX-1071.3.

(c) For tests where the output signal (M_3) exceeds the detectable range of the system (i.e., output signal is off scale), the system leakage rate shall be reported

[1] System background noise. For definition of symbols, see Nonmandatory Appendix A.

as being "greater than the detectable range of the system" and the item under test fails.

IX-1072 Alternative Technique

IX-1072.1 System Correction Factor. For helium mass spectrometer leak indicator meters in leakage rate units, a System Correction Factor (SCF) may be utilized if it is desired to utilize the acutal indicator meter leakage rate units in lieu of converting the readings to divisions [e.g., the values of M_1, M_2, M_3, and M_4 are directly read from the helium mass spectrometer in std cm^3/s (Pa m^3/s)].

IX-1072.2 Alternative Formulas. The following formulas shall be used in lieu of those described in IX-1062:

(a) Preliminary Calibration (per IX-1062.4). The preliminary system correction factor (PSCF) shall be calculated as follows:

$$PSCF = CL / (M_1 - M_2)$$

(b) Final Calibration (per IX-1062.5). The final system correction factor (FSCF) shall be calculated as follows:

$$FSCF = CL / (M_4 - M_3)$$

If the FSCF has decreased below the PSCF by more than 35%, the instrument shall be cleaned and/or repaired, recalibrated, and the component retested.

(c) System Measured Leakage Rate (per IX-1071.5). The system leakage rate shall be determined as follows:

$$Q = \frac{(FSCF \times M_3) \times 100}{\%TG} \text{ std cm}^3/\text{s (Pa m}^3/\text{s)}$$

IX-1080 EVALUATION

Unless otherwise specified by the referencing Code Section, the component tested is acceptable when the measured leakage rate Q is equal to or less than 1×10^{-6} std cm^3/s (1×10^{-7} Pa m^3/s) of helium.

IX-1081 Leakage

When the leakage rate exceeds the permissible value, all welds or other suspected areas shall be retested using a tracer probe technique. All leaks shall be marked and temporarily sealed to permit completion of the tracer probe retest. The temporary seals shall be of a type which can be readily and completely removed after testing has been completed.

IX-1082 Repair/Retest

The component shall then be vented and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

01

ARTICLE 10 — APPENDIX X ULTRASONIC LEAK DETECTOR TEST

X-1000 INTRODUCTION

This technique describes the use of an ultrasonic leak detector to detect the ultrasonic energy produced by the flow of a gas from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures.

(a) Due to the low sensitivity [maximum sensitivity of 10^{-2} std cm^3/s (10^{-3} Pa m^3/s)] of this technique, it should not be utilized for the acceptance testing of vessels that will contain lethal or hazardous substances.

(b) This is a semiquantitative method used to detect and locate leaks and shall not be considered quantitative.

TABLE X-1021
REQUIREMENTS OF AN ULTRASONIC LEAK TESTING PROCEDURE

Requirement	Essential Variable	Non-Essential Variable
Instrument Manufacturer & Model	X	
Leak standard (decrease in size only)	X	
Pressurizing gas	X	
Test pressure (decrease in pressure only)	X	
Soak time (decrease in time only)	X	
Scanning distance (increase in distance only)	X	
Scanning rate (increase in rate only)	X	
Signaling device		X
Personnel Qualification		X

X-1020 GENERAL

X-1021 Written Procedure Requirements

X-1021.1 Requirements. Ultrasonic leak testing shall be performed in accordance with a written procedure which shall, as a minimum, contain the requirements listed in Table X-1021. The written procedure shall establish a single value, or range of values, for each requirement.

X-1021.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Table X-1021 identified as an *essential* variable, from the specified value, or range of values, shall require requalification of the written procedure. A change of a requirement identified as a *nonessential* variable from the specified value, or range of values, does not require requalification of the written procedure. All changes of the essential and nonessential elements from the value, or range of values, specified by the written procedure shall require revision of, or an addendum to, the written procedure.

X-1030 EQUIPMENT

X-1031 Instrument

An electronic ultrasonic leak detector capable of detecting acoustic energy in the range of 20 to 100 kHz shall be utilized. Leakage shall be indicated by one or more of the following signaling devices:

(a) Meter — A meter on the test instrument, or a probe, or both.

(b) Audio Device — A set of headphones that emit(s) audible indications.

X-1032 Capillary Calibration Leak Standard

A capillary type leak standard per Article 10, T-1063.2.

X-1060 CALIBRATION

X-1061 Standard Leak Size

The maximum leakage rate Q for the leak standard in X-1032 shall be 1×10^{-1} std cm^3/s (1×10^{-2} Pa m^3/s), unless otherwise specified by the referencing Code Section.

X-1062 Warm-up

The detector shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibration.

X-1063 Scanning Rate

The leak standard shall be attached to a pressure regulated gas supply and the pressure set to that to be used for the test. The detector shall be calibrated by directing the detector/probe towards the leak standard at the maximum scanning distance to be utilized during testing and noting the meter deflection and/or pitch of the audible signal as the detector/probe is scanned across the leak standard. The scanning rate shall not exceed that which can detect leakage rate Q from the leak standard.

X-1064 Frequency and Sensitivity

Unless otherwise specified by the referencing Code Section, the sensitivity of the detector shall be verified before and after testing, and at intervals of not more than 4 hr during testing. During any verification check, should the meter deflection or audible signal indicate that the detector/probe cannot detect leakage per X-1063, the instrument shall be recalibrated and areas tested after the last satisfactory calibration check shall be retested.

X-1070 TEST

X-1071 Location of Test

The component to be tested shall, if possible, be removed or isolated from other equipment or structures that could generate ambient or system noise that can drown out leaks.

X-1072 Soak Time

Prior to testing, the test pressure shall be held a minimum of 15 min.

X-1073 Scanning Distance

After the required soak time per X-1072, the detector shall be passed over the test surface. The scanning distance shall not exceed that utilized to determine the maximum scanning rate in X-1063.

X-1074 Scanning Rate

The maximum scanning rate shall be as determined in X-1063.

X-1075 Leakage Detection

Leakage shall be indicated and detected according to X-1031.

X-1080 EVALUATION

X-1081 Leakage

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the allowable rate of 1×10^{-1} std cm^3/s (1×10^{-2} Pa m^3/s).

X-1082 Repair/Retest

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

X-1090 DOCUMENTATION

X-1091 Examination Report

The report of examination shall contain the following information:

(a) procedure ID and revision;
(b) manufacturer and model number of instrument;
(c) calibration leak standard size and serial number;
(d) pressurizing gas and test pressure;
(e) soak time;
(f) maximum scanning distance and rate;
(g) map or record of rejectable leakage or areas cleared;
(h) identification of welds or areas scanned;
(i) examination personnel identity;
(j) date of examination.

X-1092 Performance Demonstration Report

Performance demonstrations, when required by the referencing Code Section, shall be documented.

ARTICLE 10
NONMANDATORY APPENDIX

APPENDIX A — SUPPLEMENTARY LEAK TESTING FORMULA SYMBOLS

01 A-10 APPLICABILITY OF THE FORMULAS

(a) The formulas in this Article provide for the calculated leak rate(s) for the technique used.

(b) The symbols defined below are used in the formulas of the appropriate Appendix.

(1) System sensitivity calculation:

S_1 = preliminary sensitivity (calculation of sensitivity), std cm^3/s/div (Pa m^3/s/div)

S_2 = final sensitivity (calculation of sensitivity), std cm^3/s/div (Pa m^3/s/div)

(2) System measured leakage rate calculation:

Q = measured leakage rate of the system (corrected for tracer gas concentration), std cm^3/s (Pa m^3/s)

(3) System Correction Factors:

$PSCF$ = Preliminary System Correction Factor

$FSCF$ = Final System Correction Factor

(4) Tracer gas concentration:

$\%TG$ = concentration of Tracer Gas, %

(5) Calibrated standard:

CL = calibrated leak leakage rate, std cm^3/s (Pa m^3/s)

(6) Instrument reading sequence:

M_1 = meter reading before test with calibrated leak open to the component [divisions, or std cm^3/s (Pa m^3/s)]

M_2 = meter reading before test with calibrated leak closed to component [divisions, or std cm^3/s (Pa m^3/s)] (system background noise reading)

M_3 = meter reading (registering component leakage) with calibrated leak closed [divisions, or std cm^3/s (Pa m^3/s)]

M_4 = meter reading (registering component leakage) with calibrated leak open [divisions, or std cm^3/s (Pa m^3/s)]

ARTICLE 11

Figures

Tables

Mandatory Appendices

Figure

Nonmandatory Appendix

ARTICLE 11
ACOUSTIC EMISSION EXAMINATION OF FIBER-REINFORCED PLASTIC VESSELS

T-1110 SCOPE

(a) This Article describes or references requirements which are to be used in applying acoustic emission (AE) examination of new and inservice fiber reinforced plastic (FRP) vessels under pressure, vacuum, or other applied stress.

(b) Test pressure used during examination shall not exceed 1.5 times the maximum allowable working pressure (MAWP). Vacuum testing can be full design vacuum. These values are subordinate to stress values in specific procedures outlined in Section X, Part T, Rules Covering Testing, of the ASME Boiler and Pressure Vessel Code.

(c) This Article is limited to vessels with glass or other reinforcing material contents greater than 15% by weight.

T-1120 GENERAL

(a) When this Article is specified by a referencing Code Section, the method described in this Article shall be used together with Article 1, General Requirements. Definitions of terms used in this Article are found in Mandatory Appendix III of this Article.

(b) Discontinuities located with AE shall be evaluated by other methods, e.g., visual, ultrasonic, liquid penetrant, etc., and shall be repaired and retested as appropriate.

T-1121 Vessel Conditioning

For tanks and pressure vessels that have been stressed previously, the operating pressure and/or load shall be reduced prior to testing according to the schedule shown in Table T-1121. In order to properly evaluate the AE examination, the maximum operating pressure or load on the vessel during the past year must be known, and recorded.

TABLE T-1121
REQUIREMENTS FOR REDUCED OPERATING LEVEL IMMEDIATELY PRIOR TO EXAMINATION

Percent of Operating Maximum Pressure and/or Load	Time Spent at Percent of Maximum Pressure and/or Load
10 or less	12 hr
20	18 hr
30	30 hr
40	2 days
50	4 days
60	7 days

EXAMPLE:
For an inservice vessel, two factors must be known prior to making a test:
(1) The maximum operating pressure or load during the past year
(2) The test pressure

Table T-1121 is used as follows. The reduced pressure is divided by the maximum operating pressure and the quantity is expressed as a percent. This value is entered in the first column and the corresponding row in the second column shows the time required at the reduced pressure, prior to making an AE test. When the ratios fall between two values in the second column the higher value is used.

T-1122 Vessel Stressing

Arrangements shall be made to stress the vessel to the design pressure and/or load. The rate of application of stress and load shall be sufficient to expedite the examination with the minimum extraneous noise. Holding stress levels is a key aspect of an acoustic emission examination. Accordingly, provision must be made for holding the pressure and/or load at designated checkpoints.

(a) Atmospheric Vessels. Process liquid is the preferred fill medium for atmospheric vessels. If water must replace the process liquid, the designer and user

shall be in agreement on the procedure to achieve acceptable stress levels.

(b) Vacuum Vessel Stressing. A controllable vacuum pump system is required for vacuum tanks.

T-1123 Vessel Support

All vessels shall be examined in their operating position and supported in a manner consistent with good engineering practice. Flat bottomed vessels examined in other than the intended location shall be mounted on a noise-isolating pad on a concrete base or equivalent during the examination.

T-1124 Environmental Conditions

The minimum acceptable vessel wall temperature is 40°F (4°C) during the examination. Evaluation criteria are based above 40°F (4°C). For vessels designed to operate above 120°F (49°C), the test fluid shall be within ±10°F (5.6°C) of the design operating temperature. [At the option of the owner, the vessel test pressure may be increased to compensate for testing at elevated temperatures (120°F) (49°C).] Sufficient time shall be allowed before the start of the test for the temperature of the vessel shell and the test fluid to reach equilibrium.

T-1125 Noise Elimination

Noise sources in the test frequency and amplitude range, such as rain, spargers, and foreign objects contacting the vessels, must be minimized since they mask the AE signals emanating from the structure. The filling inlet should be at the lowest nozzle or as near to the bottom of the vessel as possible, i.e., below the liquid level.

T-1126 Instrumentation Settings

Settings shall be determined as described in Appendix II of this Article.

T-1127 Sensors

(a) Sensor Mounting. The location and spacing of the sensor are in T-1141(c). The sensors shall be placed in the designated locations with the couplant specified in the testing procedure between the sensor and test article. Assure that adequate couplant is applied. The sensor shall be held in place utilizing methods of attachment which do not create extraneous signals, as specified in the test procedure. Suitable adhesive systems are those whose bonding and acoustic coupling effectiveness have been demonstrated. The attachment method shall provide support for the signal cable (and preamplifier) to prevent the cable(s) from stressing the sensor or causing loss of coupling.

(b) Surface Contact. Sensors shall be mounted directly on the vessel surface, or integral waveguides shall be used. (Possible signal losses may be caused by coatings such as paint and encapsulants, as well as by construction surface curvature and surface roughness at the contact area.)

(c) High and Low Frequency Channels. An AE instrument channel is defined as a specific combination of sensor, preamplifier, filter, amplifier, and cable(s). Both high and low frequency channels shall be used. High frequency channels shall be used for detection and evaluation of AE sources. Low frequency channels shall be used to evaluate the coverage by high frequency sensors.

(d) High Frequency Sensors. (See Appendix I-1111.) Several high frequency channels shall be used for zone location of emission sources. This is due to greater attenuation at higher frequencies.

(e) Low Frequency Sensors. (See Appendix I-1112.) At least two low frequency channels shall be used. If significant activity is detected on the low frequency channels and not on high frequency channels, high frequency sensor location shall be evaluated by the examiner.

T-1128 Procedure Requirements 01

Acoustic emission examination shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable:

(a) material and configurations to be examined including dimensions and product form;
(b) method for determination of sensor locations;
(c) sensor locations;
(d) couplant;
(e) method of sensor attachment;
(f) sensor type, frequency, and locations;
(g) acoustic emission instrument type and frequency;
(h) description of system calibration;
(i) data to be recorded and method of recording;
(j) report requirements;
(k) post-examination cleaning;
(l) qualification of the examiner(s).

T-1130 EQUIPMENT AND SUPPLIES

(a) The AE system consists of sensors, signal processing, display, and recording equipment. (See Appendix I.)

(b) The system shall be capable of recording AE counts and AE events above a threshold within a frequency range of 25 kHz–300 kHz and have sufficient channels to localize AE sources. It may incorporate (as an option) peak amplitude detection.

NOTE: Event detection is required for each channel.

Amplitude distributions are recommended for flaw characterization. The AE system is further described in Appendix I.

(c) Capability for measuring time and pressure shall be provided and recorded. The pressure and/or vacuum (in the vessel) shall be continuously monitored to an accuracy of ±2% of the maximum test pressure.

T-1140 APPLICATION REQUIREMENTS

T-1141 Vessels

(a) Equipment. (See T-1130 and Mandatory Appendix I.)

(b) System Calibration. (See Mandatory Appendix II.)

(1) Attenuation Characterization. Typical signal propagation losses shall be determined according to one of the following techniques. These techniques provide a relative measure of the attenuation. The peak amplitude from a pencil break may vary with surface hardness, resin condition, fiber orientation, and cure.

(2) For acoustic emission instrumentation with amplitude analysis:

Select a representative region of the vessel away from manways, nozzles, etc. Mount a high frequency AE sensor and locate points at distances of 6 in. (152 mm) and 12 in. (305 mm) from the center of the sensor along a line parallel to one of the principal directions of the surface fiber (if applicable). Select two additional points at 6 in. (152 mm) and 12 in. (305 mm) along a line inclined 45 deg. to the direction of the original points. At each of the four points, break 0.3 mm 2H pencil leads and record peak amplitude. A break shall be done at an angle of approximately 30 deg. to the test surface with a 0.1 in. (2.5 mm) lead extension. This amplitude data from successive lead breaks shall be part of the report.

(3) For systems without amplitude analysis:

Select a representative region of the vessel away from manways, nozzles, etc. Mount a high frequency AE sensor and break 0.3 mm pencil leads along a line parallel to one of the principal directions of the surface fibers.

Record the distances from the center of the sensor at which the recorded amplitude equals the reference amplitude and the threshold of acoustic emission detectability (see Appendix II). Repeat this procedure along a line inclined 45 deg. to the direction of the original line. This distance data shall be part of the report.

(c) Sensor Locations and Spacings. Locations on the vessel shell are determined by the need to detect structural flaws at critical sections, e.g., high stress areas, geometric discontinuities, nozzles, manways, repaired regions, support rings, and visible flaws. High frequency sensor spacings are governed by the attenuation of the FRP material. Sensor location guidelines for typical tank types are given in Nonmandatory Appendix A.

(1) Sensor Spacing. The recommended high frequency sensor spacing on the vessel shall be not greater than three times the distance at which the recorded amplitude from the attenuation characterization equals the threshold of detectability (see Appendix II). Low frequency sensors shall be placed in areas of low stress and at a maximum distance from one another.

(d) Systems Performance Check

(1) Sensor Coupling and Circuit Continuity Verification. Verification shall be performed following sensor mounting and system hookup and immediately following the test. A record of the verifications shall be recorded in the report.

(2) Peak Amplitude Response. The peak amplitude response of each sensor-preamplifier combination to a repeatable simulated acoustic emission source shall be taken and recorded following sensor mounting. The peak amplitude of the simulated event at a specific distance greater than 3 in. (76 mm) from each sensor shall not vary more than 6 dB from the average of all the sensors.

(3) Post-test verification using the procedure in (d)(2) above shall be done and recorded for the final report.

T-1142 Examination Procedure

(a) General Guidelines. The vessel is subjected to programmed increasing stress levels to a predetermined maximum while being monitored by sensors that detect acoustic emission caused by growing structural discontinuities.

Rates of filling and pressurization shall be controlled so as not to exceed the strain rate specified by the referencing Code Section.

The desired pressure will be attained with a liquid. Pressurization with a gas (air, N_2, etc.) is not permitted. A suitable manometer or other type gage shall be used to monitor pressure. Vacuum shall be attained with a suitable vacuum source.

A quick-release valve shall be provided to handle any potential catastrophic failure condition.

(b) Background Noise. Background noise should be identified, minimized, and recorded.

(1) Background Noise of Check Prior to Loading. AE monitoring of the vessel is required to identify and determine the level of spurious signals following the completion of the system performance check and prior to stressing the vessel. A recommended monitoring period is 10 min to 30 min. If background noise is excessive, the source of the noise shall be eliminated or the examination terminated.

(2) Background Noise During Examination. In the AE examiner's analysis of examination results, background noise shall be noted and its effects on test results evaluated. Sources of background noise include liquid splashing into a vessel; a fill rate that is too high; pumps, motors, agitators, and other mechanical devices; electromagnetic interference; and environment (rain, wind, etc.).

(c) Stressing

(1) Atmospheric Vessel Loading. Stressing sequences for new atmospheric vessels and vacuum vessels are shown in Figs. T-1142(c)(1)(a) and (b). The test algorithm-flowchart for this class of vessels is given in Fig. T-1142(c)(1)(c).

(2) Pressure Vessel Stressing. Pressure vessels which operate with superimposed pressures greater than 14.7 psi above atmospheric shall be stressed as shown in Fig. T-1142(c)(2)(a). The test algorithm flowchart for this class of tanks is given in Fig. T-1142(c)(2)(b).

(3) For all vessels, the final stress hold shall be for 30 min. The vessel should be monitored continuously during this period.

(d) AE Activity. If significant [see T-1183(b)] AE activity is detected during the test on low frequency channels, and not on high frequency channels, the examiner may relocate the high frequency channels.

(e) Test Termination. Departure from a linear count/load relationship shall signal caution. If the AE count rate increases rapidly with load, the vessel shall be unloaded and the test terminated. [A rapidly (exponentially) increasing count rate indicates uncontrolled continuing damage and is indicative of impending failure.]

T-1160 CALIBRATION (See Mandatory Appendix II)

T-1180 EVALUATION

T-1181 Evaluation Criteria

The acoustic emission criteria shown in Table T-1181 are set forth as a basis for assessing the severity of structural flaws in FRP vessels. These criteria are based only on high frequency sensors. Low frequency sensors are used to monitor the entire vessel.

T-1182 Emissions During Load Hold E_H

The criterion based on emissions during load hold is particularly significant. Continuing emissions indicate continuing damage. Fill and other background noise will generally be at a minimum during a load hold.

T-1183 Felicity Ratio Determination

The felicity ratio is obtained directly from the ratio of the load at onset of emission and the maximum prior load. The felicity ratio is not measured during the first loading of pressure, atmospheric, or vacuum vessels.

(a) During the first loading of FRP vessels, the felicity ratio is measured from the unload/reload cycles. For subsequent loadings, the felicity ratio is obtained directly from the ratio of the load at onset of emission and the previous maximum load. A secondary felicity ratio is determined from the unload/reload cycles.

(b) The criterion based on felicity ratio is important for inservice vessels. The criterion provides a measure of the severity of previously induced damage. The onset of "significant" emission is used for determining measurement of the felicity ratio, as follows:

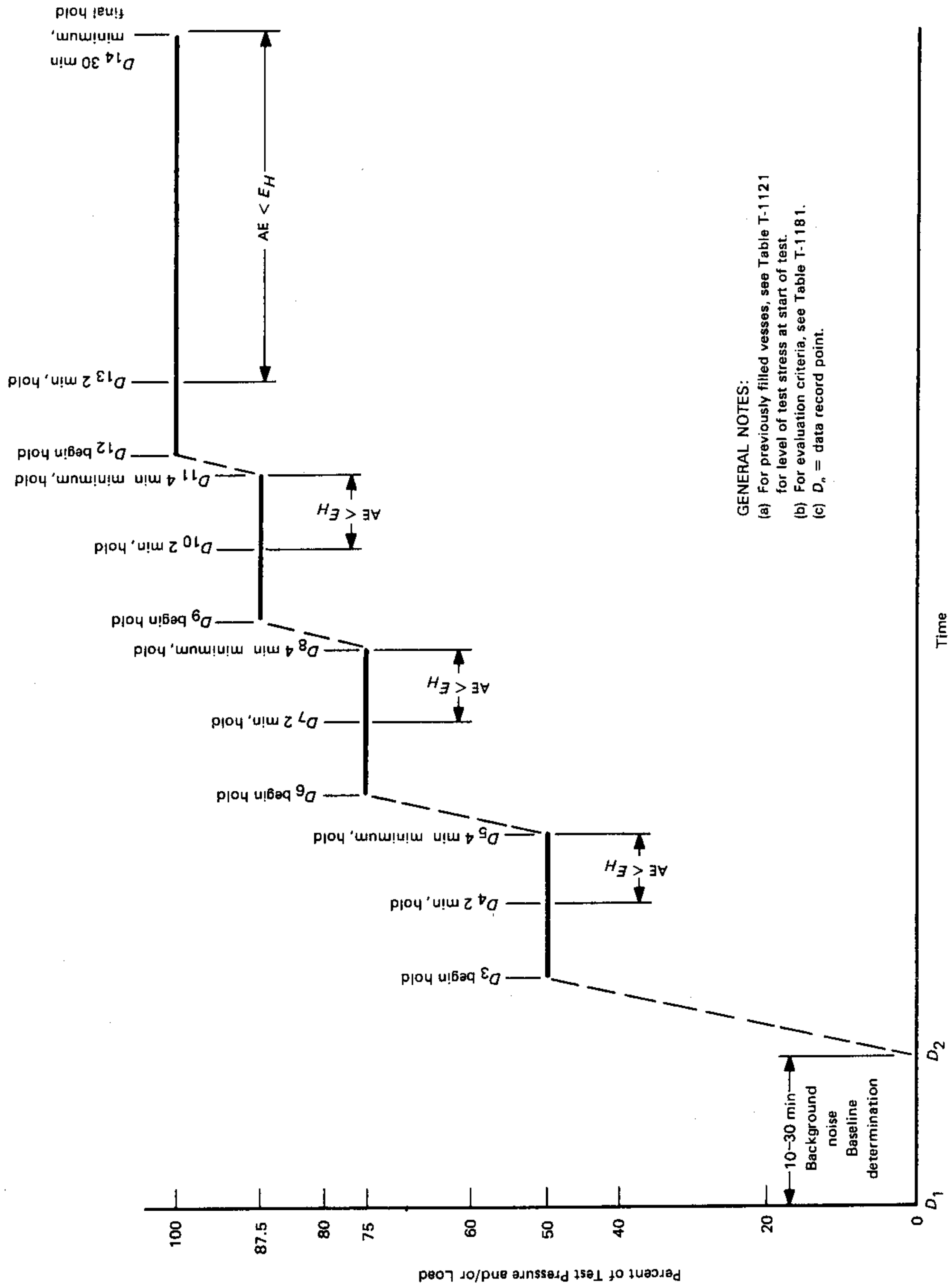
(1) more than 5 bursts of emission during a 10% increase in stress;

(2) more than $N_c/25$ counts during a 10% increase in stress, where N_c is the count criterion defined in Appendix II-1140;

(3) emission continues at a stress hold. For the purpose of this guideline, a short (1 min or less) nonprogrammed load hold can be inserted in the procedure.

T-1184 High Amplitude Events Criterion

The high amplitude events criterion is often associated with fiber breakage and is indicative of major structural



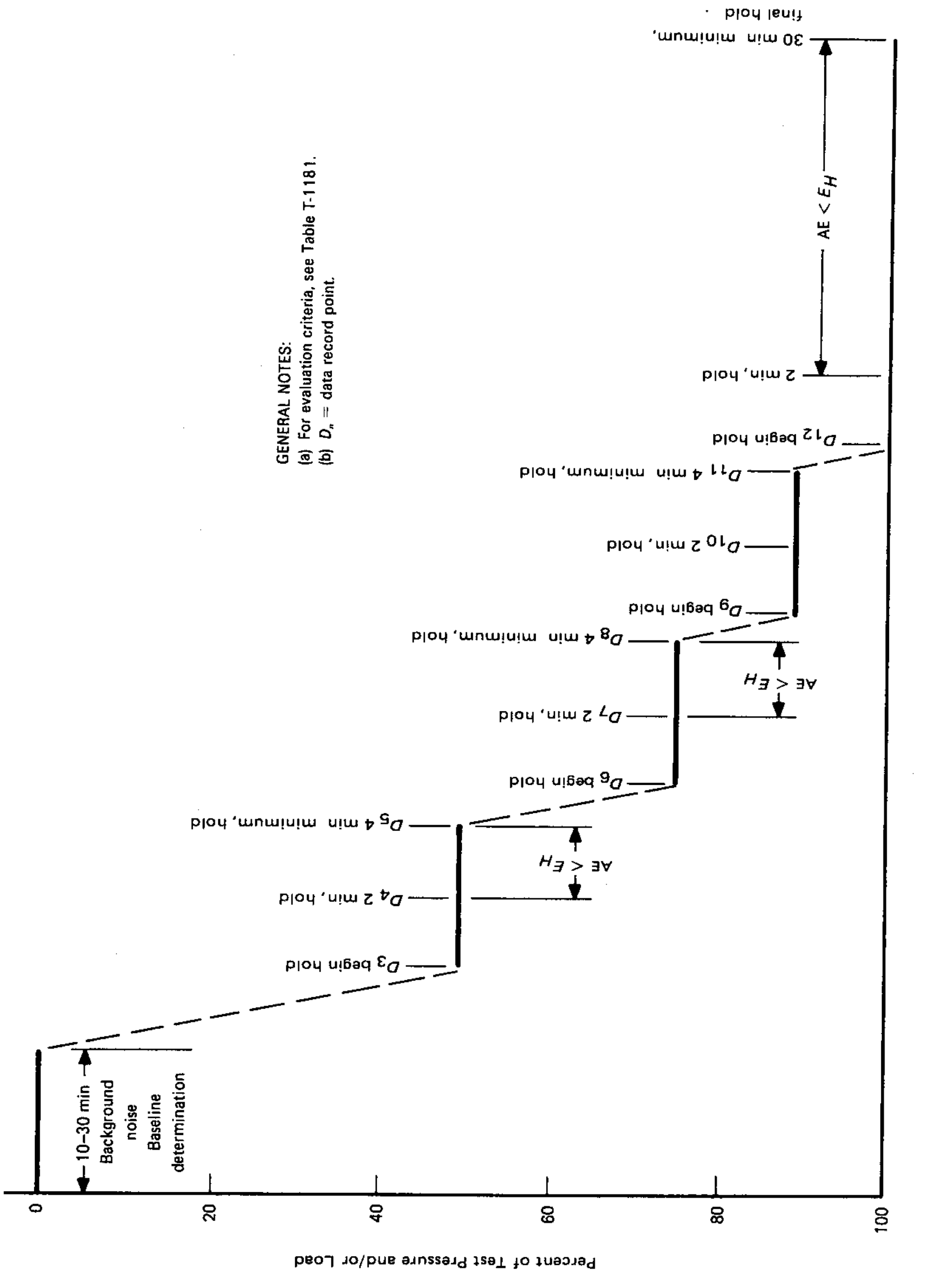
GENERAL NOTES:

(a) For previously filled vesses, see Table T-1121 for level of test stress at start of test.

(b) For evaluation criteria, see Table T-1181.

(c) D_n = data record point.

FIG. T-1142(c)(1)(a) ATMOSPHERIC VESSELS STRESSING SEQUENCE



GENERAL NOTES:
(a) For evaluation criteria, see Table T-1181.
(b) D_n = data record point.

FIG. T-1142(c)(1)(b) VACUUM VESSELS STRESSING SEQUENCE

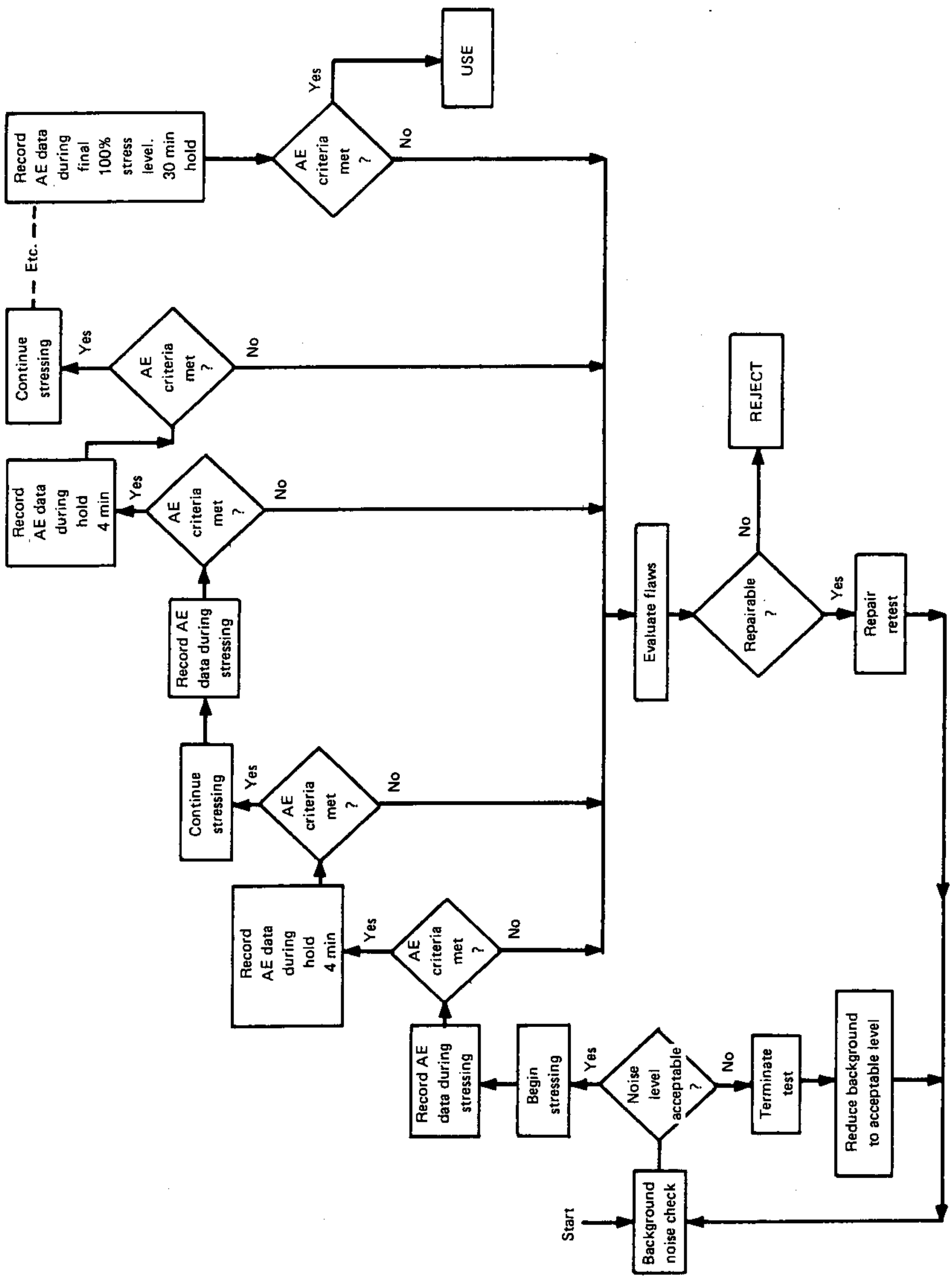
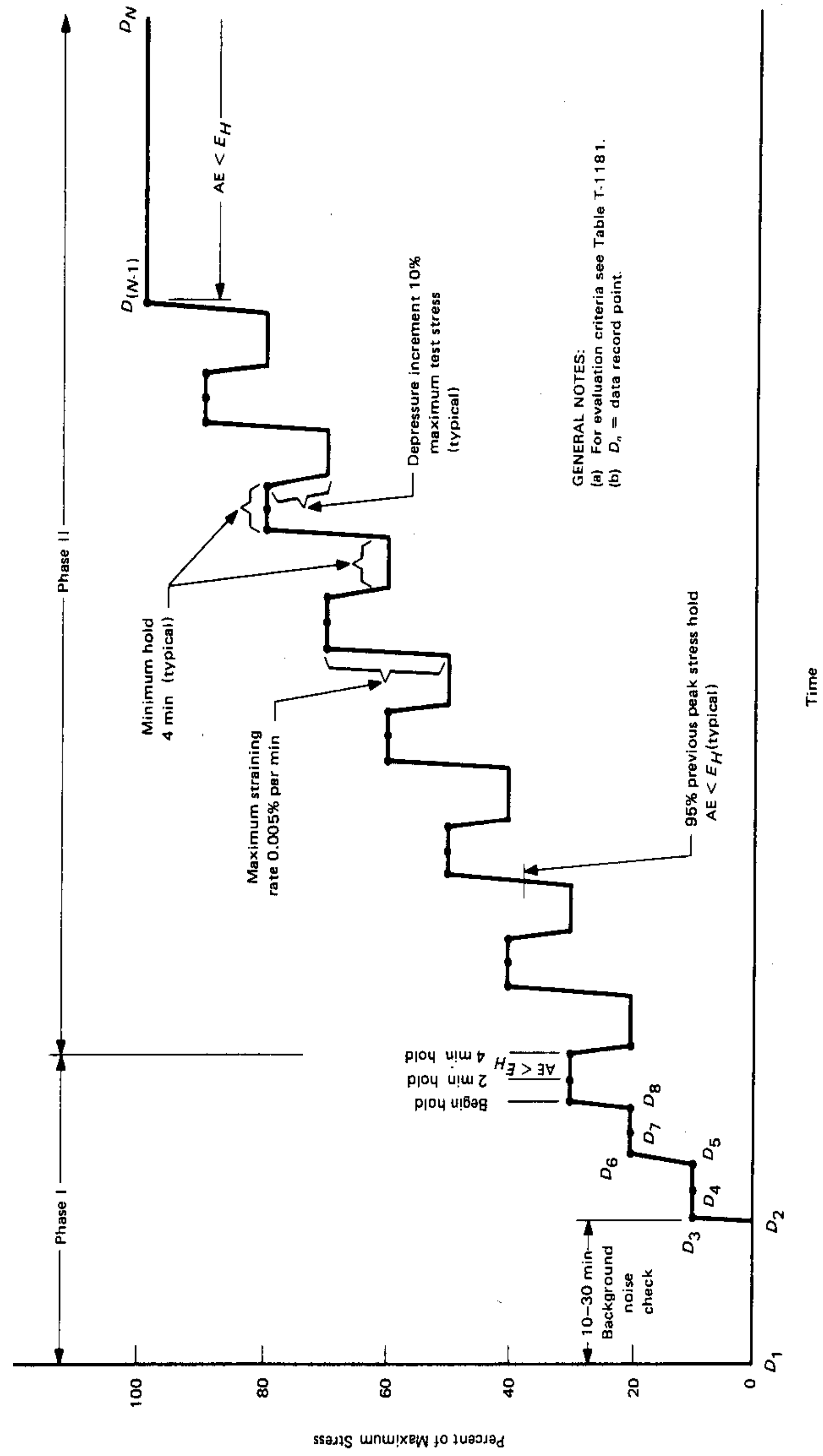


FIG. T-1142(c)(1)(c) TEST ALGORITHM — FLOWCHART FOR ATMOSPHERIC VESSELS



GENERAL NOTES:
(a) For evaluation criteria see Table T-1181.
(b) D_n = data record point.

FIG. T-1142(c)(2)(a) PRESSURE VESSEL STRESSING SEQUENCE

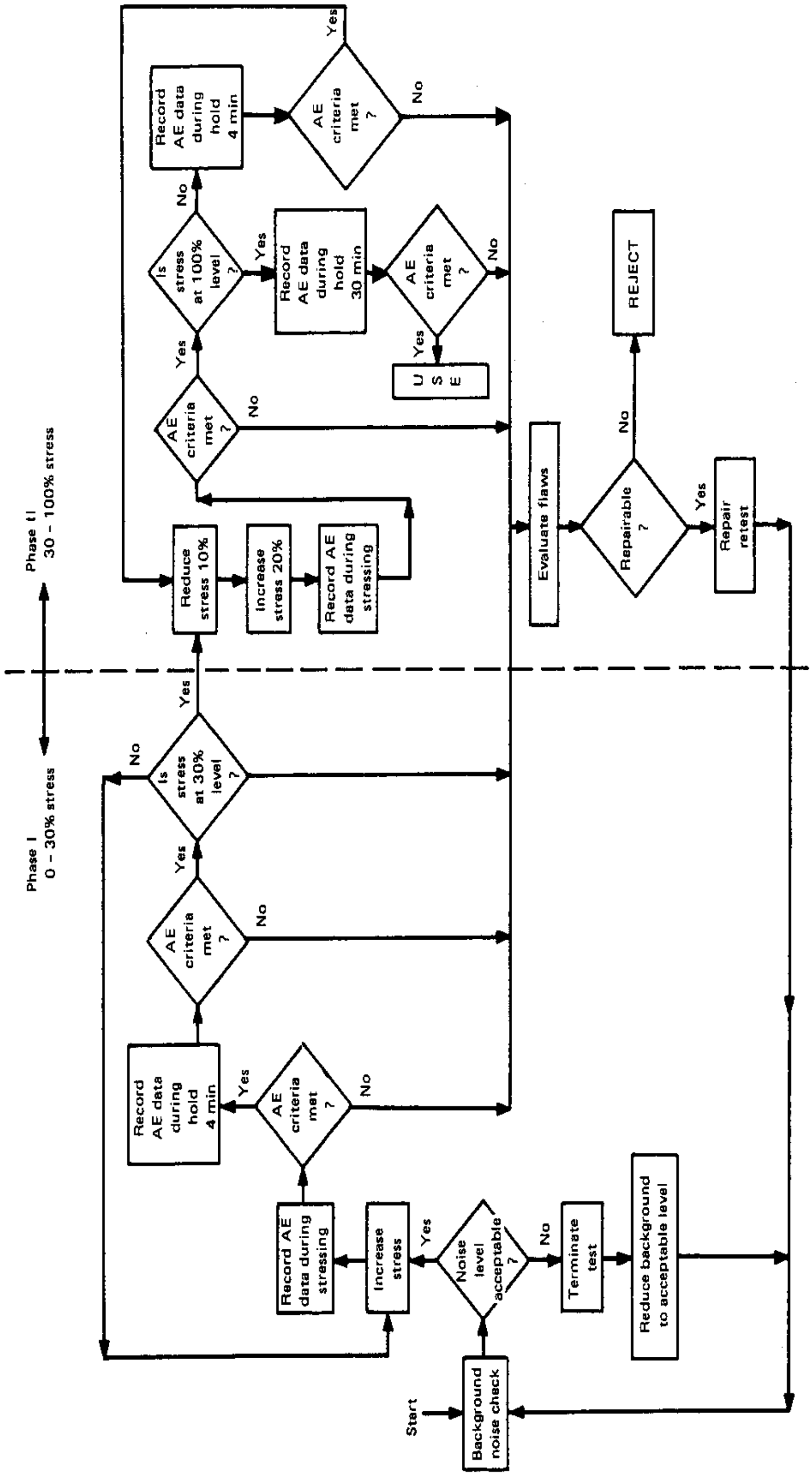


FIG. T-1142(c)(2)(b) ALGORITHM — FLOWCHART FOR PRESSURE VESSELS

TABLE T-1181
EVALUATION CRITERIA
Atmospheric (Liquid Head) and Additional[1] Superimposed Pressure

	First Loading	Subsequent Loading	
Emissions during hold	Less than E_H events beyond time T_H, none having an amplitude greater than A_M [Note (2)]	Less than E_H events beyond time T_H	Measure of continuing permanent damage [Note (3)]
Felicity ratio	Greater than felicity ratio F_A	Greater than felicity ratio F_A	Measure of severity of previous induced damage
Total [Note (4)]	Not excessive [Note (5)]	Less than N_c total counts	Measure of overall damage during a load cycle
M [Note (6)]	No events with a duration greater than M	No events with a duration greater than M	Measure of delamination, adhesive bond failure, and major crack growth
Number of events greater than reference amplitude threshold	Less than E_A events	Less than E_A events	Measure of high energy microstructure failures. This criterion is often associated with fiber breakage.

GENERAL NOTE: A_M, E_A, E_H, F_A, N_c, and M are acceptance criteria values specified by the referencing Code Section; T_H is specified hold time.

NOTES:
(1) Above atmospheric
(2) See Appendix II-1140 for definition of A_M.
(3) Permanent damage can include microcracking, debonding, and fiber pull out.
(4) Varies with instrumentation manufacturer; see Appendix II for functional definition of N_c. Note that counts criterion N_c may be different for first and subsequent fillings.
(5) Excessive counts are defined as a significant increase in the rate of emissions as a function of load. On a plot of counts against load, excessive counts will show as a departure from linearity.
(6) If used, varies with instrumentation manufacturer; see Appendix II-1150 for functional definition.

damage in new vessels. For inservice and previously stressed vessels, emissions during a stress hold and felicity ratio are important.

T-1185 Total Counts Criterion

The criteria based on total counts are valuable for pressure or atmospheric and vacuum vessels. Pressure vessels, particularly during first stressing, tend to be noisy.

Excessive counts, as defined in Table T-1181, are important for all vessels, and are a warning of impending failure.

T-1190 DOCUMENTATION

T-1191 Report

The report shall include the following:

(a) complete identification of the vessel, including material type, source, method of fabrication, Manufacturer's name and code number, and previous history of maintenance, as well as relaxation operation data from Table T-1121, prior to testing;

(b) vessel sketch or Manufacturer's drawing with dimensions and sensor locations;

(c) test liquid employed;

(d) test liquid temperature;

(e) test sequence — load rate, hold times, and hold levels;

(f) correlation of test data with the acceptance criteria;

(g) a sketch or Manufacturer's drawings showing the location of any zone not meeting the evaluation criteria;

(h) any unusual effects or observations during or prior to the test;

(i) date(s) of test;

(j) name(s) and qualifications of the test operator(s);

(k) complete description of AE instrumentation including Manufacturer's name, model number, sensor type, system gain, etc.

T-1192 Record

(a) A permanent record of AE data includes:

(1) AE events above threshold vs time for zones of interest;

(2) total counts vs time, etc.;

(3) signal propagation loss.

(b) The AE data shall be maintained with the records of the vessel.

ARTICLE 11
MANDATORY APPENDICES

APPENDIX I — INSTRUMENTATION PERFORMANCE REQUIREMENTS

I-1110 AE SENSORS

AE sensors shall be temperature stable over the range of use which may be 40°F–200°F (4°C–93°C), and shall not exhibit sensitivity changes greater than 3 dB over this range. Sensors shall be shielded against radio frequency and electromagnetic noise interference through proper shielding practice and/or differential (anticoincident) element design. Sensors shall have a frequency response with variations not exceeding 4 dB from the peak response.

I-1111 High Frequency Sensors

These sensors shall have a resonant response at 100 kHz–200 kHz. Minimum sensitivity shall be −80 dB referred to 1 volt/microbar, determined by face-to-face ultrasonic calibration. AE sensors used in the same test should not vary in peak sensitivity more than 3 dB from the average.

I-1112 Low Frequency Sensors

These sensors shall have a resonant response between 25 kHz and 75 kHz. Minimum sensitivity shall be comparable to, or greater than, commercially available high sensitivity accelerometers with resonant response in that frequency range. In service, these sensors may be wrapped or covered with a sound-absorbing medium to limit interference by airborne noise, if permitted in the procedure used in making the examination.

I-1120 SIGNAL CABLE

The signal cable from sensor to preamp shall not exceed 6 ft (1.8 m) in length and shall be shielded against electromagnetic interference. This requirement is omitted where the preamplifier is mounted in the sensor housing, or a line-driving (matched impedance) sensor is used.

I-1130 COUPLANT

Commercially available couplants for ultrasonic flaw detection accumulated above second threshold may be used (high setting adhesives may also be used, provided couplant sensitivity is not significantly lower than with fluid couplants). Couplant selection should be made to minimize changes in coupling sensitivity during a test. Consideration should be given to testing time and the surface temperature of the vessel. The couplant and method of attachment are specified in the written procedure.

I-1140 PREAMPLIFIER

The preamplifier, when used, shall be mounted in the vicinity of the sensor, or may be in the sensor housing. If the preamp is of differential design, a minimum of 40 dB of common-mode noise rejection shall be provided. Unfiltered frequency response shall not vary more than 3 dB over the frequency range of 25 kHz–300 kHz, and over the temperature range of 40°F–125°F (4°C–52°C). For sensors with integral preamps, frequency response characteristics shall be confined to a range consistent with the operational frequency of the sensor.

I-1150 FILTERS

Filters shall be of the band pass or high pass type, and shall provide a minimum of −24 dB/octave signal attenuation. Filters may be located in preamplifier or post-preamplifier circuits, or may be integrated into the component design of the sensor, preamp, or processor to limit frequency response. Filters and/or integral design characteristics shall insure that the principal processing frequency for high frequency sensors is not

less than 100 kHz, and for low frequency sensors not less than 25 kHz.

I-1160 POWER-SIGNAL CABLE

The cable providing power to the preamplifier and conducting the amplified signal to the main processor shall be shielded against electromagnetic noise. Signal loss shall be less than 1 dB per 100 ft (30.5 m) of cable length. The recommended maximum cable length is 500 ft (152 m) to avoid excessive signal attenuation. Digital or radio transmission of signals is allowed if consistent with standard practice in transmitting those signal forms.

I-1161 Power Supply

A stable grounded electrical power supply, meeting the specifications of the instrumentation, shall be used.

I-1170 MAIN AMPLIFIER

The main amplifier, if used, shall have signal response with variations not exceeding 3 dB over the frequency range of 25 kHz–300 kHz, and temperature range of 40°F–125°F (4°C–52°C). The written procedure shall specify the use and nomenclature of the main amplifier.

The main amplifier shall have adjustable gain, or an adjustable threshold for event detection and counting.

I-1180 MAIN PROCESSOR

I-1181 General

The main processor(s) shall have a minimum of two active data processing circuits through which high frequency and low frequency sensor data will be processed independently. If independent channels are used, the processor shall be capable of processing events and counts on each channel. No more than two sensors may be commoned into a single preamplifier.

If a summer or mixer is used, it shall provide a minimum processing capability for event detection on eight channels (preamp inputs).

Low frequency sensor information will be processed for emission activity. Total counts will be processed from the high frequency sensors only. Events accumulated above second threshold (high amplitude events) will be processed from the high frequency sensors only. The high amplitude signal threshold may be established through signal gain reduction, threshold increase, or peak amplitude detection.

(a) Threshold. The AE instrument used for examination shall have a threshold control accurate to within ±2 dB over its useful range.

(b) Counts. The AE instrument used for examination shall detect counts over a set threshold within an accuracy of ±5%.

(c) Events. The AE instrument used for examination shall be capable of continuously measuring 100 events ±1 event/sec, over a set threshold.

(d) Peak Amplitude. When peak amplitude detection is used, the AE instrument used for examination shall measure the peak amplitude within an accuracy of ±2 dB over a set threshold.

(e) M. The AE instrument used for examination shall be capable of measuring an M value (if used).

(f) Field Performance Verification. At the beginning of each vessel test the performance of each channel of the AE instrument shall be checked using an electronic waveform generator and a stress wave generator.

(g) Waveform Generator. This device shall input a sinusoidal burst-type signal of measurable amplitude, duration, and carrier frequency. As a minimum, it shall be able to verify system operation for threshold, counts, and if used, duration, and peak amplitude measurements over the range of 25 kHz–200 kHz.

(h) Stress Wave Generator. This device shall transmit a stress wave pulse into the sensor. AE instrumentation response shall be within 5 dB of the response of the same sensor model when new.

The AE channel response to a single lead break shall be within 5 dB of the channel response of the same sensor model when new.

I-1182 Peak Amplitude Detection

If peak amplitude detection is practiced, comparative calibration must be established per the requirements of Appendix II. Usable dynamic range shall be a minimum of 60 dB with 5 dB resolution over the frequency band of 100 kHz–300 kHz, and the temperature range of 40°F–125°F (4°C–52°C). Not more than 2 dB variation in peak detection accuracy shall be allowed over the stated temperature range. Amplitude values may be stated in volts or dB, but must be referenced to a fixed gain output of the system (sensor or preamp).

I-1183 Signal Outputs and Recording

The processor as a minimum shall provide outputs for permanent recording of total counts for high frequency sensors, events by channel (zone location), and total events above the reference amplitude threshold for high

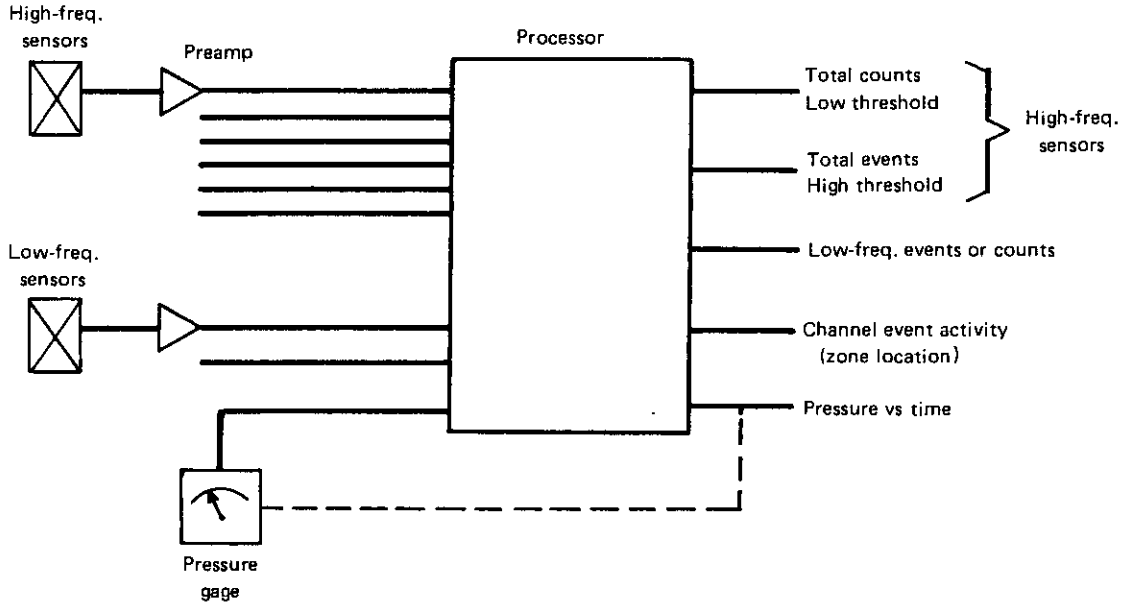


FIG. I-1183 SAMPLE OF SCHEMATIC OF AE INSTRUMENTATION FOR VESSEL EXAMINATION

frequency sensors. A sample schematic is shown in Fig. I-1183.

APPENDIX II — INSTRUMENT CALIBRATION

II-1110 GENERAL

The performance and threshold definitions vary for different types of acoustic emission equipment. Parameters such as counts, amplitude, energy, and M vary from manufacturer to manufacturer, and from model to model by the same manufacturer. This Appendix defines procedures for determining the threshold of acoustic emission detectability, reference amplitude threshold, and count criterion N_c.

The procedures defined in this Appendix are intended for baseline instrument calibration at 60°F to 80°F (16°C to 27°C). Instrumentation users shall develop calibration techniques traceable to the baseline calibration outlined in this Appendix. For field use, electronic calibrators, small portable samples (acrylic or similar), can be carried with the equipment and used for periodic checking of sensor, preamplifier, and channel sensitivity.

II-1120 THRESHOLD

Threshold of acoustic emission detectability shall be determined using a 4 ft × 6 ft × $\frac{1}{2}$ in. (1.2 m × 1.8 m × 13 mm) 99% pure lead sheet. The sheet shall be suspended clear of the floor. The threshold of detectability is defined as the average measured amplitude of ten events generated by 0.3 mm pencil (2H) lead break at a distance of 4 ft 3 in. (1.3 m) from the sensor. A break shall be done at an angle of approximately 30 deg. to the test surface with a 0.1 in. (2.5 mm) lead extension. The sensor shall be mounted 6 in. (152 mm) from the 4 ft (1.2 m) side and mid-distance between the 6 ft (1.8 m) sides.

II-1130 REFERENCE AMPLITUDE THRESHOLD

For large amplitude events, the reference amplitude threshold shall be determined using a 10 ft × 2 in. × $\frac{3}{4}$ in. (3.0 m × 51 mm × 19 mm) clean, mild steel bar. The bar shall be supported at each end by elastomeric, or similar, isolating pads. The reference amplitude threshold is defined as the average measured amplitude of ten events generated by a 0.3 mm pencil (2H) lead break at a distance of 7 ft (2.1 m) from the sensor (see Appendix II-1120). A break shall be done at an

angle of approximately 30 deg. to the test surface with a 0.1 in. (2.5 mm) lead extension. The sensor shall be mounted 12 in. (305 mm) from the end of the bar on the 2 in. (51 mm) wide surface.

II-1140 COUNT CRITERION N_c AND A_M VALUE

The count criterion N_c shall be determined either before or after the test using a 0.3 mm pencil (2H) lead broken on the surface of the vessel. A break shall be done at an angle of approximately 30 deg. to the test surface with a 0.1 in. (2.5 mm) lead extension. Calibration points shall be chosen so as to be representative of different constructions and thicknesses and should be performed above and below the liquid line (if applicable), and away from manways, nozzles, etc.

Two calibrations shall be carried out for each calibration point. One calibration shall be in the principal direction of the surface fibers (if applicable), and the second calibration shall be carried out along a line at 45 deg. to the direction of the first calibration. Breaks shall be at a distance from the calibration point so as to provide an amplitude decibel value A_M midway between the threshold of detectability (see Appendix II-1120) and reference amplitude threshold (see Appendix II-1130).

The count criterion N_c shall be based on the counts recorded from a defined (referencing Code Section) number of 0.3 mm pencil (2H) lead breaks at each of the two calibration points.

When applying the count criterion, the count criterion value, which is representative of the region where activity is observed, should be used.

II-1150 MEASUREMENT OF M

M is a measure of delamination, adhesive bond failure, or major crack growth. Different techniques are used by different instrument manufacturers for measuring M. The units of the M value will vary depending upon the techniques and instrument that are used. Numerical values of M are normally defined from an electronically generated input signal. The value of M will be specified by the referencing Code Section.

II-1160 FIELD PERFORMANCE

As installed on the vessel, no channel shall deviate by more than 6 dB from the average peak response of all channels when lead breaks, or other simulated transient sources, are introduced 6 in. (152 mm) from the sensor.

APPENDIX III — GLOSSARY OF TERMS FOR ACOUSTIC EMISSION EXAMINATION OF FIBER-REINFORCED PLASTIC VESSELS

III-1110 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms related to examination of fiber-reinforced plastic vessels with acoustic emission.

III-1120 GENERAL REQUIREMENTS

(a) The standard terminology for Nondestructive Examinations, ASTM E 1316, has been adopted by the Committee as SE-1316.

(b) SE-1316 defines the terms that are used in conjunction with this Article.

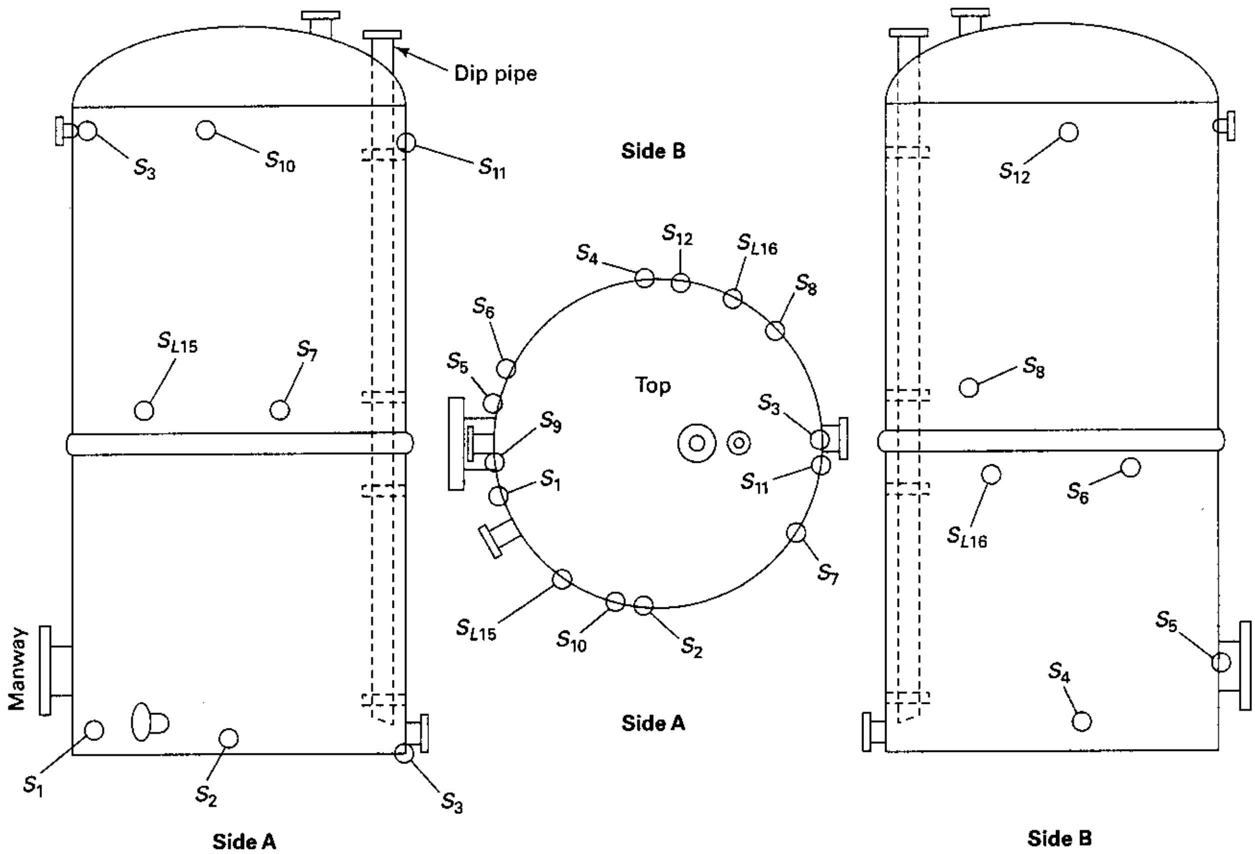
(c) For general terms, such as *interpretation, flaw, discontinuity, evaluation*, etc., refer to Article 1, Mandatory Appendix I.

ARTICLE 11
NONMANDATORY APPENDIX

Appendix A begins on the next page.

APPENDIX A
SENSOR PLACEMENT GUIDELINES

CASE 1 – ATMOSPHERIC VERTICAL VESSEL



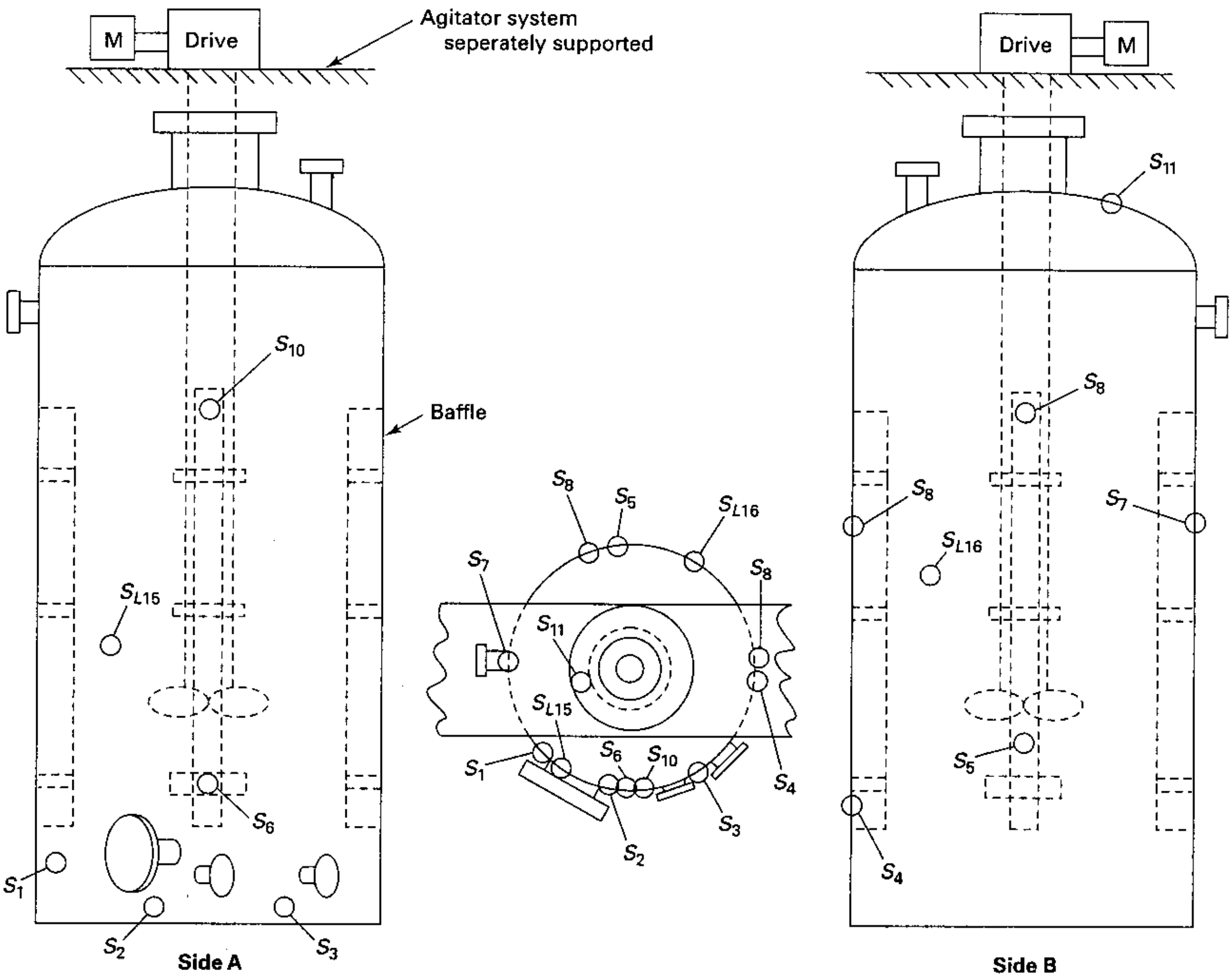
GUIDELINES:

(1) The bottom knuckle region is critical due to discontinuity stresses. Locate sensors to provide adequate coverage, e.g., approximately every 90 deg. and 6 in. to 12 in. (152 mm to 305 mm) away from knuckle on shell.

(2) The secondary bond joint areas are suspect, e.g., nozzles, manways, shell butt joint, etc. For nozzles and manways, the preferred sensor location is 3 in. to 6 in. (76 mm to 152 mm) from intersection with shell and below. The shell butt joint region is important. Locate the two high frequency sensors up to 180 deg. apart—one above and one below the joint.

(3) The low frequency sensors shown as S_{L15} and S_{L16} should be located at vessel mid-height—one above and one below the joint. Space as far apart as possible—up to 180 deg. and at 90 deg. to the high frequency pair.

CASE 2 – ATMOSPHERIC VERTICAL VESSEL



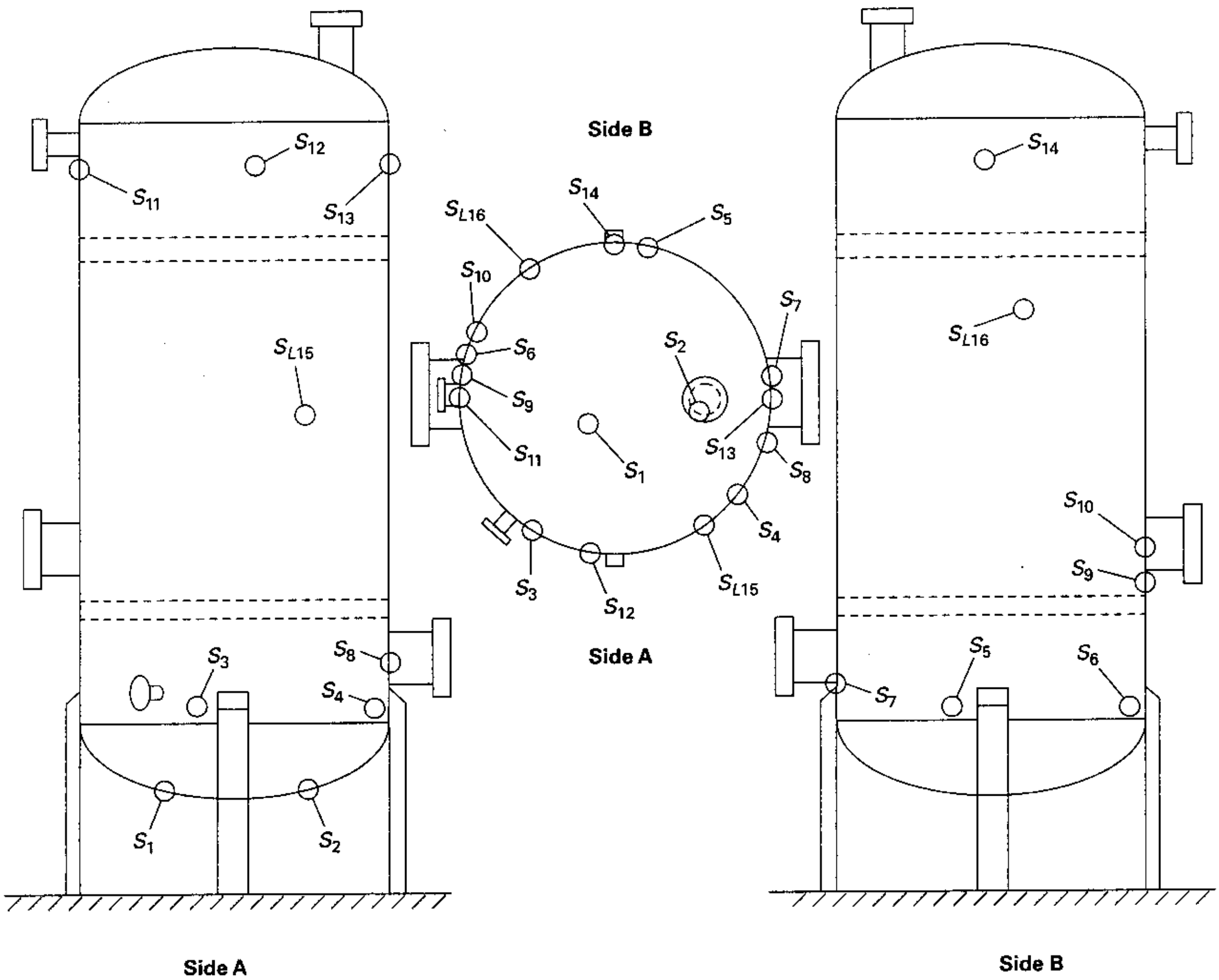
GUIDELINES:

(1) The bottom knuckle region is critical due to discontinuity stresses. Locate sensors to provide adequate coverage, e.g., approximately every 90 deg. and 6 in. to 12 in. (152 mm to 305 mm) away from the knuckle on shell. In this example, sensors are so placed that the bottom nozzles, manways, and baffle areas plus the knuckle regions are covered.

(2) The secondary bond joint areas are suspect, e.g., nozzles, manways, and baffle attacthments to shell. See the last sentence of above for bottom region coverage in this example. Note sensor adjacent to agitator shaft top manway. This region should be checked with agitator on.

(3) The low frequency sensors shown as S_{L15} and S_{L16} should be located at vessel mid-height, one above and one below joint. They should be spaced as far apart as possible—up to 180 deg.

CASE 3 – ATMOSPHERIC / PRESSURE VESSEL



GUIDELINES:

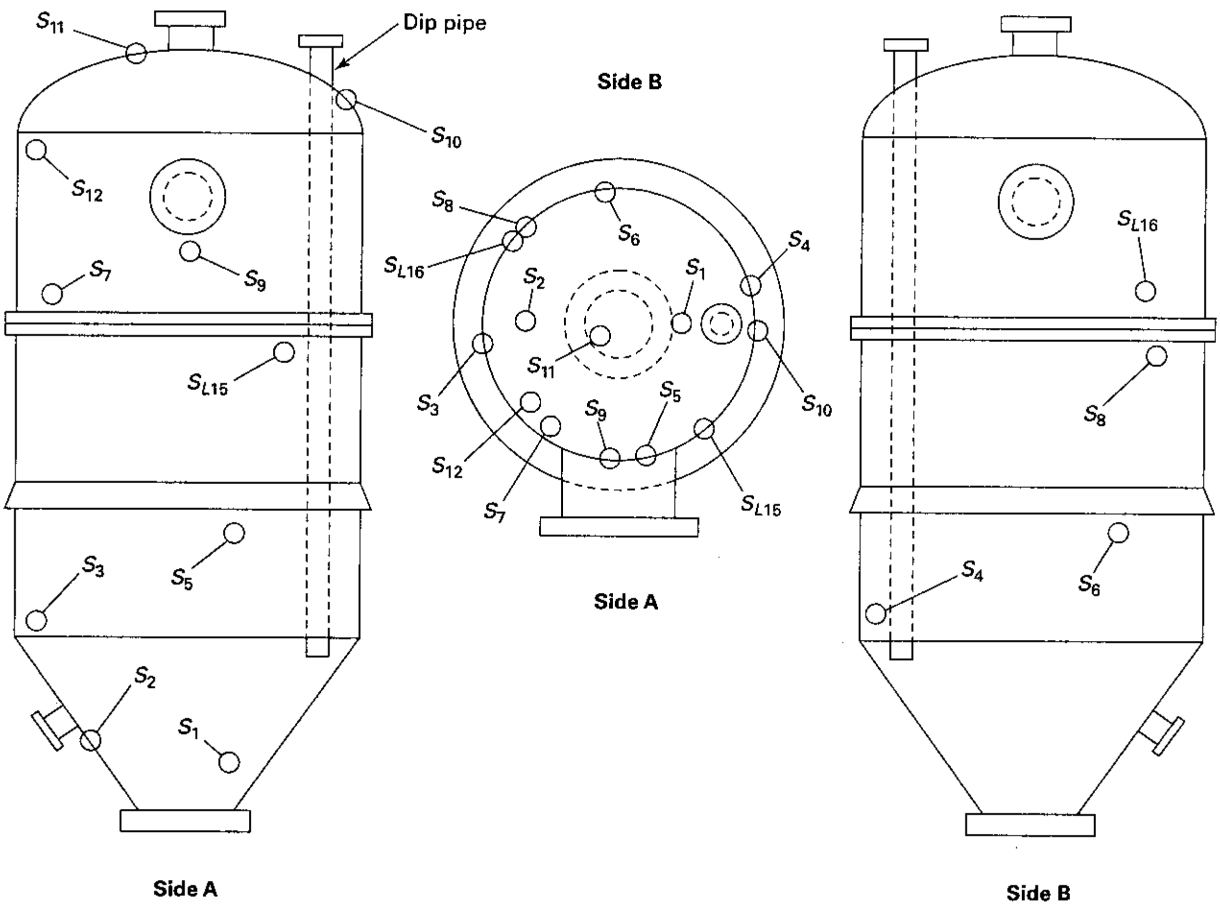
(1) The bottom head is highly stressed. Locate two sensors approximately as shown.

(2) The bottom knuckle region is critical. Locate sensors to provide adequate coverage, e.g., approximately every 90 deg. and 6 in. to 12 in. (152 mm to 305 mm) away from knuckle on shell. The top knuckle region is similarly treated.

(3) The secondary bond areas are suspect, i.e., nozzles, manways, and leg attachments. For nozzles and manways, the preferred sensor location is 3 in. to 6 in. (76 mm to 152 mm) from the intersection with shell and below. For leg attachments, there should be a sensor within 12 in. of the shell-leg interface.

(4) The low frequency sensors shown as S_{L15} and S_{L16} should be located at vessel mid-height—one above and one below joint. They should be spaced as far apart as possible up to 180 deg.

CASE 4 - ATMOSPHERIC / PRESSURE VERTICAL VESSEL

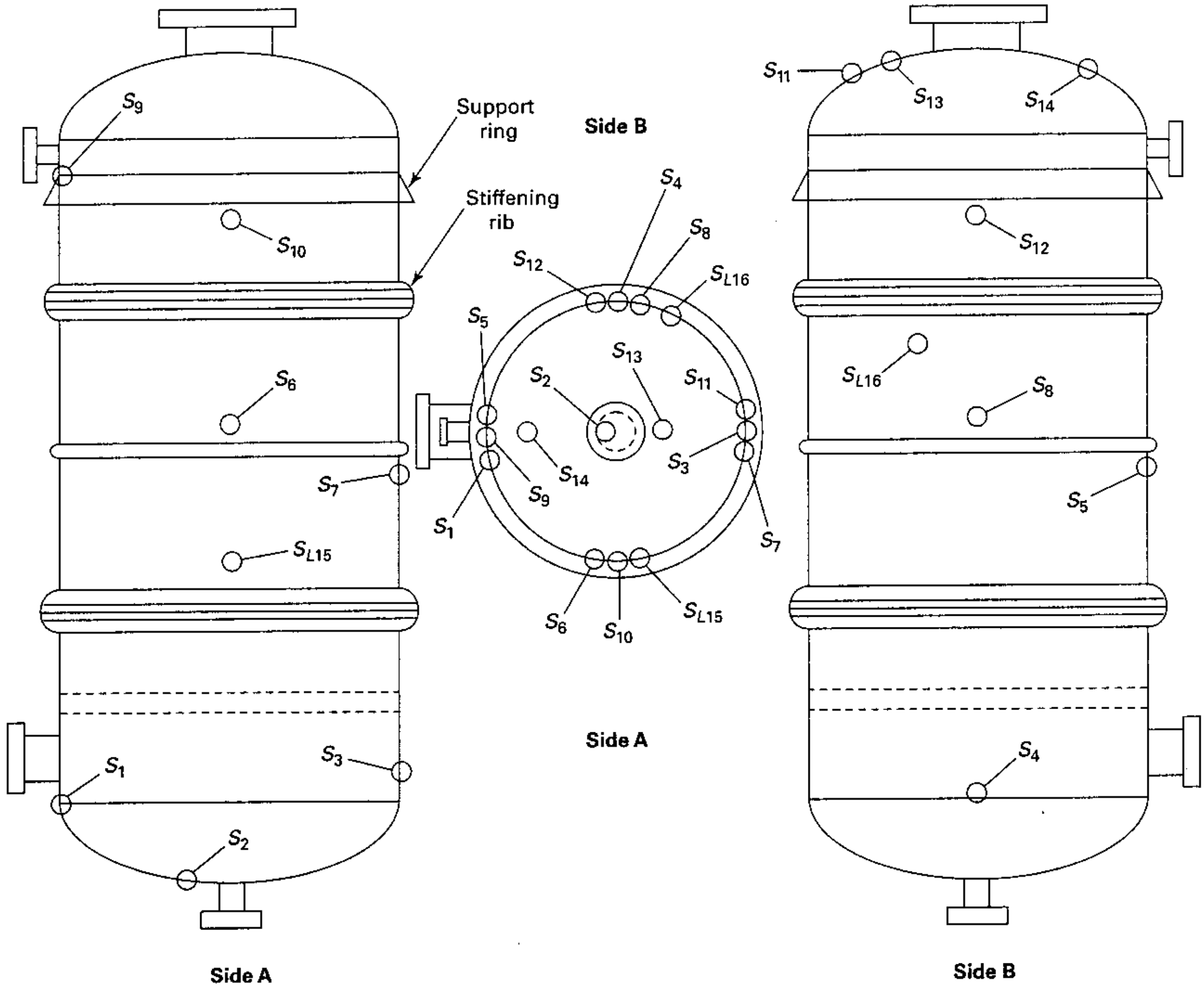


GUIDELINES:

(1) The secondary bond joint areas are suspect, i.e., nozzles, manways, and body flanges. Particularly critical in this vessel are the bottom manway and nozzle. For nozzles and manways, the preferred sensor location is 3 in. to 6 in. (76 mm to 152 mm) from intersection with shell and below. The bottom flange in this example is covered by sensor 3 in. to 6 in. (76 mm to 152 mm) above the manway. The body flange is covered by low frequency sensors S_{L15} and S_{L16} — one above and one below the body flange and spaced as far apart as possible — up to 180 deg. Displaced approximately 90 deg. from this pair and spaced up to 180 deg. apart are the two high frequency sensors — one above and one below the flange.

(2) The knuckle regions are suspect due to discontinuity stresses. Locate sensors to provide adequate coverage, i.e., approximately every 90 deg. and 3 in. to 6 in. (76 mm to 152 mm) away from knuckle on shell.

CASE 5 – ATMOSPHERIC / VACUUM VERTICAL VESSEL



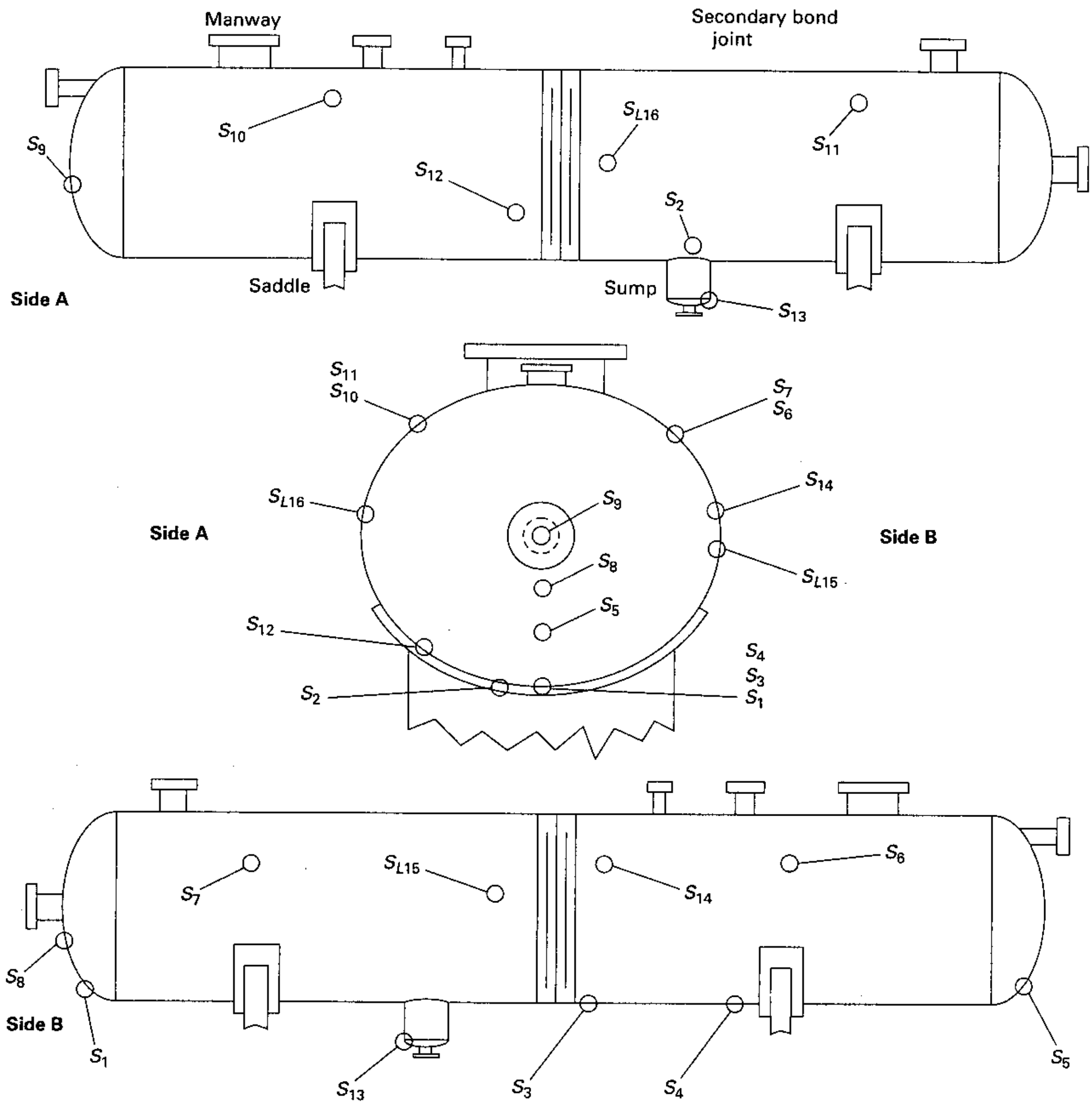
GUIDELINES:

(1) The knuckle regions are suspect due to discontinuity stresses. Locate sensors to provide adequate coverage, i.e., approximately every 90 deg. and 6 in. to 12 in. (152 mm to 305 mm) away from knuckle on shell.

(2) The secondary bond joint areas are critical, e.g., nozzles, manways, and shell butt joints. For nozzles and manways, the preferred sensor location is 3 in. to 6 in. (76 mm to 152 mm) from the intersection with the shell (or head) and below, where possible. The shell butt joint region is important. Locate sensors up to 180 deg. apart where possible and alternately above and below joint.

(2) The low frequency sensors shown as S_{L15} and S_{L16} should be located at vessel mid-height—one above and one below the joint. They should be spaced as far apart as possible—up to 180 deg. and at 90 deg. to other pair.

CASE 6 – ATMOSPHERIC / PRESSURE HORIZONTAL TANK



GUIDELINES:

(1) The discontinuity stresses at the intersection of the heads and the shell in the bottom region are important. Sensors should be located to detect structural problems in these areas.

(2) The secondary bond joint areas are suspect, e.g., shell butt joint, nozzles, manways, and sump. The preferred sensor location is 3 in. to 6 in. (76 mm to 152 mm) from intersecting surfaces of revolution. The shell butt joint region is important. Locate the two high frequency sensors up to 180 deg. apart—one on either side of the joint.

(3) The low frequency sensors shown as S_{L15} and S_{L16} should be located in the middle of the tank—one on either side of the joint. They should be spaced as far apart as possible, i.e., up to 180 deg. and at 90 deg. to high frequency pair.

ARTICLE 12

Figure

Table

Mandatory Appendices

Nonmandatory Appendices

ARTICLE 12
ACOUSTIC EMISSION EXAMINATION OF METALLIC VESSELS DURING PRESSURE TESTING

T-1210 SCOPE

This Article describes methods for conducting acoustic emission (AE) examination of metallic pressure vessels during acceptance pressure testing when specified by a referencing Code Section. When AE examination in accordance with this Article is specified, the referencing Code Section shall be consulted for the following specific requirements:

(a) personnel qualification/certification requirements;

(b) requirements/extent of examination and/or volume(s) to be examined;

(c) acceptance/evaluation criteria;

(d) standard report requirements;

(e) content of records and record retention.

When this Article is specified by a referencing Code Section, the AE method described in the Article shall be used together with Article 1, General Requirements. Definitions of terms used in this Article may be found in Mandatory Appendix III of this Article.

T-1220 GENERAL

T-1220.1 The principal objectives of AE examination are to locate and monitor emission sources caused by surface and internal discontinuities in the vessel wall, welds, and fabricated parts and components.

T-1220.2 All relevant indications caused by AE sources shall be evaluated by other methods of nondestructive examination.

T-1221 Vessel Stressing

Arrangements shall be made to stress the vessel using internal pressure as specified by the referencing Code Section. The rate of application of pressure shall be specified in the examination procedure and the pressurizing rate shall be sufficient to expedite the examination with minimum extraneous noise. Provisions shall be made for holding the pressure at designated hold points.

T-1222 Noise Reduction

External noise sources such as rain, foreign objects contacting the vessel, and pressurizing equipment noise must be below the system examination threshold.

T-1223 Sensors

T-1223.1 Sensor Frequency. Selection of sensor frequency shall be based on consideration of background noise, acoustic attenuation, and vessel configuration. Frequencies in the range of 100 kHz–400 kHz have been shown to be effective. (See Nonmandatory Appendix B.)

T-1223.2 Sensor Mounting. The location and spacing of the sensors are referenced in T-1243. The sensors shall be acoustically coupled using couplant specified in the written procedure. Suitable adhesive systems are those whose bonding and acoustic coupling effectiveness have been demonstrated.

When examining austenitic stainless steels, titanium, or nickel alloys, the need to restrict chloride/fluoride ion content, total chlorine/fluorine content, and sulfur content in the couplant or other materials used on the vessel surface shall be considered and limits agreed upon between contracting parties.

The sensor shall be held in place utilizing methods of attachment, as specified in the written procedure.

The signal cable and preamplifier must be supported.

T-1223.3 Surface Contact. Sensors shall be mounted directly on the vessel surface, or on integral waveguides.

T-1224 Location of Acoustic Emission Sources

T-1224.1 Sources shall be located to the specified accuracy by multichannel source location, zone location, or both, as required by the referencing Code Section.

All hits detected by the instrument shall be recorded and used for evaluation.

T-1224.2 Multichannel source location accuracy shall be within a maximum of 2 component wall thicknesses or 5% of the sensor spacing distance, whichever is greater.

01 **T-1225 Procedure Requirements**

Acoustic emission examination shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable:

(a) material and configurations to be examined, including dimensions and product form;

(b) background noise measurements;

(c) sensor type, frequency, and Manufacturer;

(d) method of sensor attachment

(e) couplant;

(f) acoustic emission instrument type and filter frequency;

(g) sensor locations;

(h) method for selection of sensor locations;

(i) description of system calibration(s);

(j) data to be recorded and method of recording;

(k) post-examination vessel cleaning;

(l) report requirements; and

(m) qualification/certification of the examiner(s).

T-1230 EQUIPMENT AND SUPPLIES

(a) The AE system consists of sensors, signal processing, display, and recording equipment (see Appendix I).

(b) Data measurement and recording instrumentation shall be capable of measuring the following parameters from each AE hit on each channel: counts above system examination threshold, peak amplitude, arrival time, and Measured Area of the Rectified Signal Envelope (MARSE). Mixing or otherwise combining the acoustic emission signals of different sensors in a common preamplifier is not permitted except to overcome the effects of local shielding. (See Nonmandatory Appendix B.) The data acquisition system shall have sufficient channels to provide the sensor coverage defined in T-1243.4. Amplitude distribution, by channel, is required for source characterization. The instrumentation shall be capable of recording the measured acoustic emission data by hit and channel number.

(c) Time and pressure shall be measured and recorded as part of the AE data. The pressure shall be continuously monitored to an accuracy of ±2% of the maximum test pressure.

(1) Analog type indicating pressure gages used in testing shall be graduated over a range not less than $1\frac{1}{2}$ times nor more than 4 times the test pressure.

(2) Digital type pressure gages may be used without range restriction provided the combined error due to calibration and readability does not exceed 1% of the test pressure.

T-1240 APPLICATION REQUIREMENTS

T-1241 Equipment

(See T-1230 and Mandatory Appendix I.)

T-1242 System Calibration

(See Mandatory Appendix II.)

T-1243 Pre-Examination Measurements

T-1243.1 On-Site System Calibration. Prior to each vessel test or series of tests, the performance of each utilized channel of the AE instrument shall be checked by inserting a simulated AE signal at each main amplifier input.

A series of tests is that group of tests using the same examination system which is conducted at the same site within a period not exceeding 8 hr or the test duration, whichever is greater.

This device shall input a sinusoidal burst-type signal of measurable amplitude, duration, and carrier frequency. As a minimum, on-site system calibration shall be able to verify system operation for threshold, counts, MARSE, and peak amplitude. Calibration values shall be within the range of values specified in Appendix I.

T-1243.2 Attenuation Characterization. An attenuation study is performed in order to determine sensor spacing. This study is performed with the test fluid in the vessel using a simulated AE source. For production line testing of identical vessels see Nonmandatory Appendix B.

The typical signal propagation losses shall be determined according to the following procedure: select a representative region of the vessel away from manways, nozzles, etc., mount a sensor, and strike a line out from the sensor at a distance of 10 ft (3 m) if possible. Break 0.3 mm (2H) leads next to the sensor and then at a 2 ft (0.6 m) interval along this line. The breaks shall be done with the lead at an angle of approximately 30 deg. to the surface and with a 0.1 in. (2.5 mm) lead extension.

T-1243.3 Sensor Location. Sensor locations on the vessel shall be determined by the vessel configuration and the maximum sensor spacing (see T-1243.4). A further consideration in locating sensors is the need to detect structural flaws at critical sections, e.g., welds, high stress areas, geometric discontinuities, nozzles, manways, repaired regions, support rings, and visible flaws. Additional consideration should be given to the possible attenuation effects of welds. See Nonmandatory Appendix B. Sensor location guidelines for zone location for typical vessel types are given in Nonmandatory Appendix A.

T-1243.4 Sensor Spacing

T-1243.4.1 Sensor Spacing for Zone Location. Sensors shall be located such that a lead break at any location in the examination area is detected by at least one sensor and have a measured amplitude not less than as specified by the referencing Code Section. The maximum sensor spacing shall be no greater than $1\frac{1}{2}$ times the threshold distance. The threshold distance is defined as the distance from a sensor at which a pencil-lead break on the vessel has a measured amplitude value equal to the evaluation threshold.

T-1243.4.2 Sensor Spacing for Multichannel Source Location Algorithms. Sensors shall be located such that a lead break at any location in the examination area is detected by at least the minimum number of sensors required for the algorithms.

T-1243.5 Systems Performance Check. A verification of sensor coupling and circuit continuity shall be performed following sensor mounting and system hookup and again immediately following the test. The peak amplitude response of each sensor to a repeatable simulated acoustic emission source at a specific distance from each sensor should be taken prior to and after the test. The measured peak amplitude should not vary more than 4 dB from the average of all the sensors. Any channel failing this check should be investigated and replaced or repaired as necessary. If during any check it is determined that the testing equipment is not functioning properly, all of the product that has been tested since the last valid system performance check shall be re-examined.

T-1244 Examination Procedure

T-1244.1 General Guidelines. The vessel is subjected to programmed increasing stress levels to a predetermined maximum while being monitored by sensors that detect acoustic emission caused by growing structural discontinuities.

T-1244.2 Background Noise. Extraneous noise must be identified, minimized, and recorded.

T-1244.2.1 Background Noise Check Prior to Loading. Acoustic emission monitoring of the vessel during intended examination conditions is required to identify and determine the level of spurious signals following the completion of the system performance check and prior to stressing the vessel. A recommended monitoring period is 15 min. If background noise is above the evaluation threshold, the source of the noise shall be eliminated or the examination terminated.

T-1244.2.2 Background Noise During Examination. In the AE examiner's analysis of examination results, background noise shall be noted and its effects on test results evaluated. Sources of background noise include:

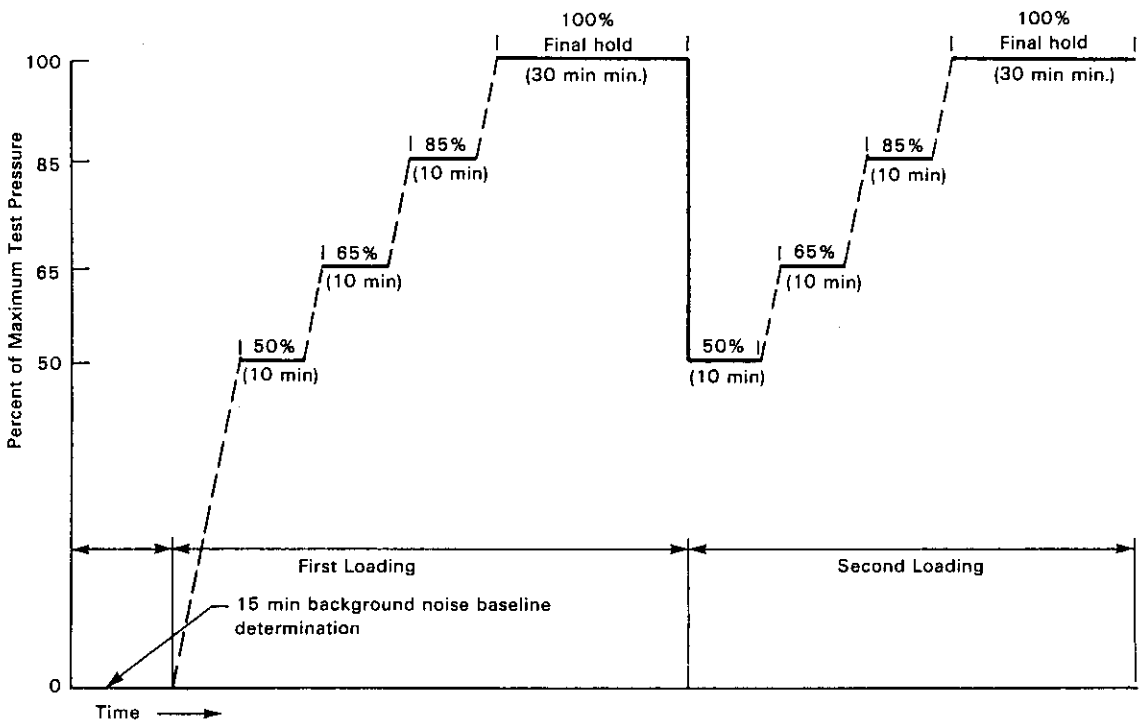
(1) liquid splashing into a vessel;
(2) a pressurizing rate that is too high;
(3) pumps, motors, and other mechanical devices;
(4) electromagnetic interference; and
(5) environment (rain, wind, etc.).

Leaks from the vessel such as valves, flanges, and safety relief devices can mask AE signals from the structure. Leaks must be eliminated prior to continuing the examination.

T-1244.3 Vessel Pressurization

T-1244.3.1 Rates of pressurization, pressurizing medium, and safety release devices shall be as specified by the referencing Code Section. The pressurization should be done at a rate that will expedite the test with a minimum of extraneous noise.

T-1244.3.2 Pressurization Sequence. The examination shall be done in accordance with the referencing Code Section. Pressure increments shall generally be to 50%, 65%, 85%, and 100% of maximum test pressure. Hold periods for each increment shall be 10 min and for the final hold period shall be at least 30 min. (See Fig. T-1244.3.2.) Normally, the pressure test will cause local yielding in regions of high secondary stress. Such local yielding is accompanied by acoustic emission which does not necessarily indicate discontinuities. Because of this, only large amplitude hits and hold period data are considered during the first loading of vessels without post-weld heat treatment (stress relief). If the first loading data indicates a possible discontinuity or is inconclusive, the vessel shall be repressurized from 50% to 100% of the test pressure with intermediate load holds at 50%, 65%, and 85%. Hold periods for the second pressurization shall be the same as for the original pressurization.



GENERAL NOTE:
During loading, increases in pressure/load levels should not exceed 10% of the maximum test pressure in 2 min.

FIG. T-1244.3.2 AN EXAMPLE OF PRESSURE VESSEL TEST STRESSING SEQUENCE

T-1244.3.3 Test Termination. Departure from a linear count or MARSE vs. load relationship should signal caution. If the AE count or MARSE rate increases rapidly with load, the vessel shall be unloaded and either the test terminated or the source of the emission determined and the safety of continued testing evaluated. A rapidly (exponentially) increasing count or MARSE rate may indicate uncontrolled, continuing damage indicative of impending failure.

T-1260 CALIBRATION

(See Mandatory Appendix II.)

T-1280 EVALUATION

T-1281 Evaluation Criteria

The AE criteria shown in Table T-1281 are set forth as one basis for assessing the significance of AE indications. These criteria are based on a specific set of AE monitoring conditions. The criteria to be used shall be as specified in the referencing Code Section.

T-1290 DOCUMENTATION

T-1291 Written Report

The report shall include the following:

(a) complete identification of the vessel, including material type, method of fabrication, Manufacturer's name, and certificate number;

(b) vessel sketch of Manufacturer's drawing with dimensions and sensor locations;

(c) test fluid employed;

(d) test fluid temperature;

(e) test sequence load rate, hold times, and hold levels;

(f) attenuation characterization and results;

(g) record of system performance verifications;

TABLE T-1281
AN EXAMPLE OF EVALUATION CRITERIA FOR ZONE LOCATION

	Emission During Load Hold	Count Rate	Number of Hits	Large Amplitude Hits	MARSE or Amplitude	Activity	Evaluation Threshold, dB
(First Loading) Pressure vessels without full postweld heat treatment	Not more than E_H hits beyond time T_H	Not applied	Not applied	Not more than E_A hits above a specified amplitude	MARSE or amplitudes do not increase with increasing load.	Activity does not increase with increasing load.	V_{TH}
Pressure vessels other than those covered above	Not more than E_H hits beyond time T_H	Less than N_T counts per sensor for a specified load increase	Not more than E_T hits above a specified amplitude	Not more than E_A hits above a specified amplitude	MARSE or amplitudes do not increase with increasing load.	Activity does not increase with increasing load.	V_{TH}

GENERAL NOTES:
(a) E_H, N_T, E_T, and E_A are specified acceptance criteria values specified by the referencing Code Section.
(b) V_{TH} is the specified evaluation threshold.
(c) T_H is the specified hold time.

(h) correlation of test data with the acceptance criteria;

(i) a sketch or Manufacturer's drawings showing the location of any zone not meeting the evaluation criteria;

(j) any unusual effects or observations during or prior to the test;

(k) date(s) of test(s);

(l) name(s) and qualifications of the test operator(s); and

(m) complete description of AE instrumentation including Manufacturer's name, model number, sensor type, instrument settings, calibration data, etc.

T-1292 Record

(a) A permanent record AE data includes:

(1) AE hits above threshold vs time and/or pressure for zones of interest;

(2) total counts vs time and/or pressure; and

(3) written reports.

(b) The AE data shall be maintained with the records of the vessel.

ARTICLE 12
MANDATORY APPENDICES

APPENDIX I — INSTRUMENTATION PERFORMANCE REQUIREMENTS

I-1210 ACOUSTIC EMISSION SENSORS

I-1210.1 General. Acoustic emission sensors in the range of 100 kHz–400 kHz shall be temperature-stable over the range of intended use, and shall not exhibit sensitivity changes greater than 3 dB over this range as guaranteed by the Manufacturer. Sensors shall be shielded against radio frequency and electromagnetic noise interference through proper shielding practice and/or differential (anticoincident) element design. Sensors shall have a frequency response with variations not exceeding 4 dB from the peak response.

I-1210.2 Sensor Characteristics. Sensors shall have a resonant response between 100 kHz–400 kHz. Minimum sensitivity shall be −80 dB referred to 1 volt/microbar, determined by face-to-face ultrasonic test.

NOTE: This method measures relative sensitivity of the sensor. Acoustic emission sensors used in the same test should not vary in peak sensitivity more than 3 dB from the average.

I-1220 SIGNAL CABLE

The signal cable from sensor to preamplifier shall not exceed 6 ft (1.8 m) in length and shall be shielded against electromagnetic interference.

I-1230 COUPLANT

Couplant selection shall provide consistent coupling efficiency during a test. Consideration should be given to testing time and the surface temperature of the vessel. The couplant and method of sensor attachment shall be specified in the written procedure.

I-1240 PREAMPLIFIER

The preamplifier shall be mounted in the vicinity of the sensor, or in the sensor housing. If the preamplifier is of differential design, a minimum of 40 dB of common-mode noise rejection shall be provided. Frequency response shall not vary more than 3 dB over the operating frequency and temperature range of the sensors.

I-1250 FILTER

Filters shall be of the band pass or high pass type and shall provide a minimum of 24 dB/octave signal attenuation. Filters shall be located in preamplifier. Additional filters shall be incorporated into the processor. Filters shall insure that the principal processing frequency corresponds to the specified sensor frequency.

I-1260 POWER-SIGNAL CABLE

The cable providing power to the preamplifier and conducting the amplified signal to the main processor shall be shielded against electromagnetic noise. Signal loss shall be less than 1 dB per 100 ft (30.5 m) of cable length. The recommended maximum cable length is 500 ft (152 m) to avoid excessive signal attenuation.

I-1270 POWER SUPPLY

A stable grounded electrical power supply, meeting the specifications of the instrumentation, shall be used.

I-1280 MAIN AMPLIFIER

The gain in the main amplifier shall be linear within 3 dB over the temperature range of 40°F to 125°F (4°C to 52°C).

I-1290 MAIN PROCESSOR

I-1291 General

The main processor(s) shall have processing circuits through which sensor data will be processed. It shall be capable of processing hits, counts, peak amplitudes, and MARSE on each channel.

(a) Threshold. The AE instrument used for examination shall have a threshold control accurate to within ±1 dB over its useful range.

(b) Counts. The AE counter circuit used for examination shall detect counts over a set threshold within an accuracy of ±5%.

(c) Hits. The AE instrument used for examination shall be capable of measuring, recording, and displaying a minimum of 20 hits/sec total for all channels for a minimum period of 10 sec and continuously measuring, recording, and displaying a minimum of 10 hits/sec total for all channels. The system shall display a warning if there is greater than a 5 sec lag between recording and display during high data rates.

(d) Peak Amplitude. The AE circuit used for examination shall measure the peak amplitude with an accuracy of ±2 dB.

(e) Energy. The AE circuit used for examination shall measure MARSE with an accuracy of ±5%. The usable dynamic range for energy shall be a minimum of 40 dB.

(f) Parametric Voltage. If parametric voltage is measured by the AE instrument, it should measure to an accuracy of 2% of full scale.

I-1292 Peak Amplitude Detection

Comparative calibration must be established per the requirements of Appendix II. Usable dynamic range shall be a minimum of 60 dB with 1 dB resolution over the frequency band width of 100 kHz to 400 kHz, and the temperature range of 40°F to 125°F (4°C to 52°C). Not more than 2 dB variation in peak detection accuracy shall be allowed over the stated temperature range. Amplitude values shall be stated in dB, and must be referenced to a fixed gain output of the system (sensor or preamplifier).

APPENDIX II — INSTRUMENT CALIBRATION AND CROSS-REFERENCING

II-1210 MANUFACTURER'S CALIBRATION

Acoustic emission system components will be provided from the Manufacturer with certification of performance specifications and tolerances.

II-1211 Annual Calibration

The instrument shall have an annual comprehensive calibration following the guidelines provided by the Manufacturer using calibration instrumentation meeting the requirements of a recognized national standard.

II-1220 INSTRUMENT CROSS-REFERENCING

The performance and threshold definitions vary for different types of AE instrumentation. Parameters such as counts, amplitude, energy, etc., vary from Manufacturer to Manufacturer and from model to model by the same Manufacturer. This section of appendix describes techniques for generating common baseline levels for the different types of instrumentation.

The procedures are intended for baseline instrument calibration at 60°F to 80°F (16°C to 27°C). For field use, small portable signal generators and calibration transducers can be carried with the equipment and used for periodic checking of sensor, preamplifier, and channel sensitivity.

II-1221 Sensor Characterization

Threshold of acoustic emission detectability is an amplitude value. All sensors shall be furnished with documented performance data. Such data shall be traceable to NBS standards. A technique for measuring threshold of detectability is described in Article XI, Appendix II.

APPENDIX III — GLOSSARY OF TERMS FOR ACOUSTIC EMISSION EXAMINATION OF METAL PRESSURE VESSELS

III-1210 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms

relating to metal pressure vessel examination with acoustic emission.

III-1220 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 defines the terms that are used in conjunction with this Article.

(c) For general terms, such as *Interpretation, Flaw, Discontinuity, Evaluation*, etc., refer to Article 1, Mandatory Appendix I.

(d) In addition to those terms listed in SE-1316, the terms listed in II-1230 are also applicable.

III-1230 REQUIREMENTS

The following Code terms are used in conjunction with this Article:

dB scale — a relative logarithmic scale of signal amplitude defined by dB V = 20 log V^{in}/V^{out}. The reference voltage is defined as 1 volt out of the sensor and V is measured amplitude in volts.

electronic waveform generator — a device which can repeatably induce a transient signal into an acoustic emission processor for the purpose of checking, verifying, and calibrating the instrument

measured area of the rectified signal envelope — a measurement of the area under the envelope of the rectified linear voltage time signal from the sensor

multi-channel source location — a source location technique which relies on stress waves from a single source producing hits at more than one sensor. Position of the source is determined by mathematical algorithms using difference in time of arrival

simulated AE source — a device which can repeatedly induce a transient elastic stress wave into the structure

threshold of detectability — a peak amplitude measurement used for cross calibration of instrumentation from different vendors

zone — the area surrounding a sensor from which AE sources can be detected

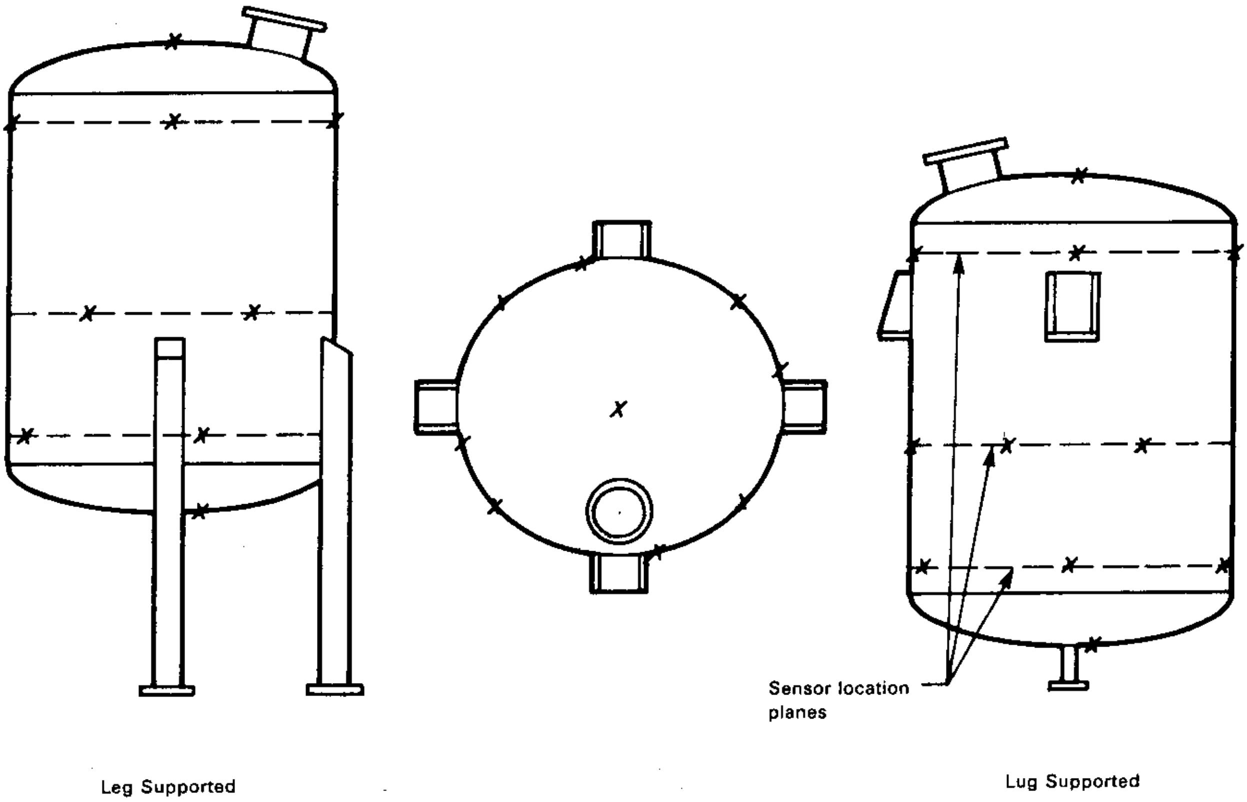
zone location — a method of locating the approximate source of emission

ARTICLE 12
NONMANDATORY APPENDICES

Appendix A begins on the next page.

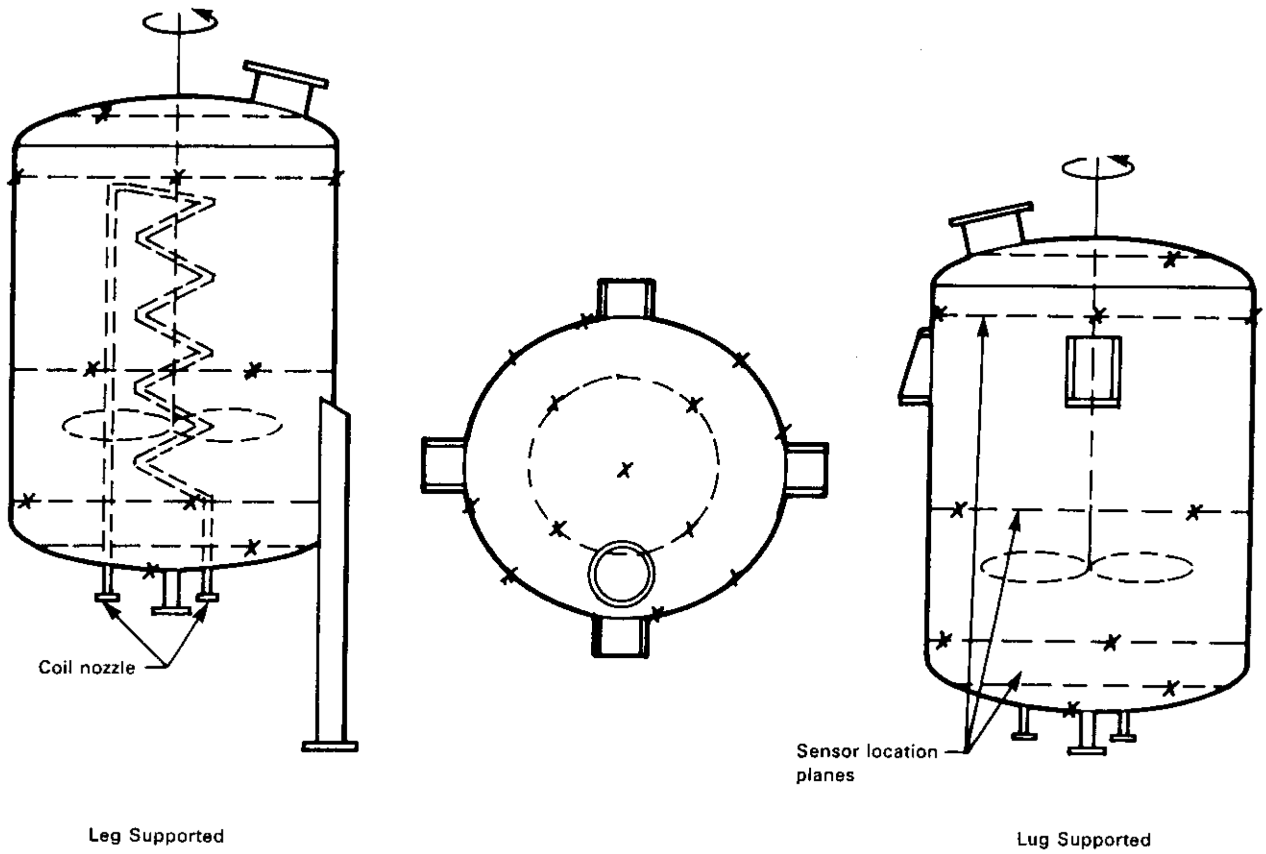
APPENDIX A
SENSOR PLACEMENT GUIDELINES

CASE 1 — VERTICAL PRESSURE VESSEL DISHED HEADS, LUG OR LEG SUPPORTED



GUIDELINES:
(1) X denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).
(2) Additional rows of sensors may be required.

CASE 2 — VERTICAL PRESSURE VESSEL DISHED HEADS, AGITATED, BAFFLED LUG, OR LEG SUPPORT



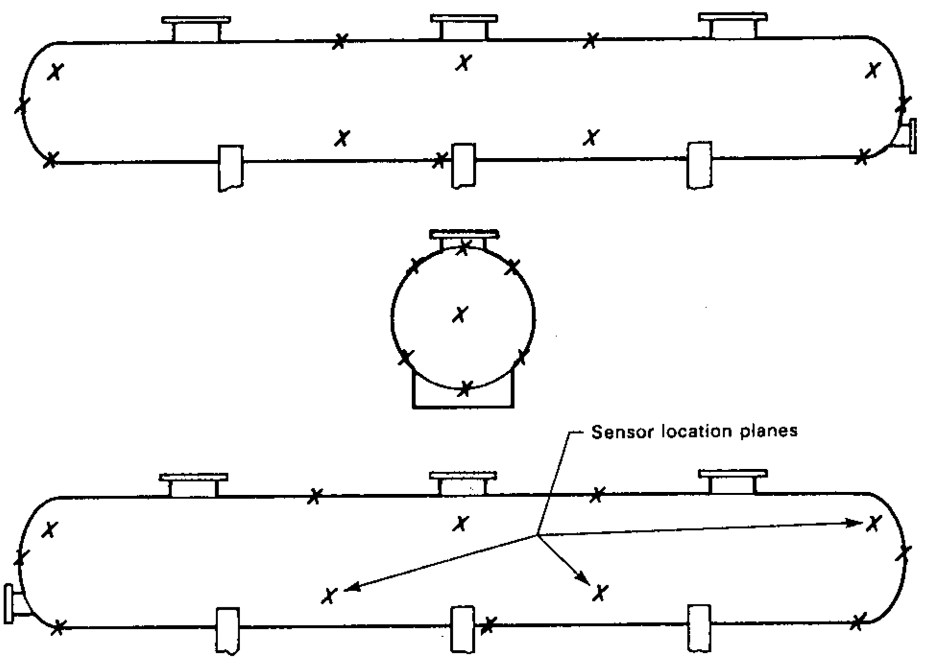
GUIDELINES:

(1) X denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).

(2) Sensors may be located on outlet to detect defects in coil.

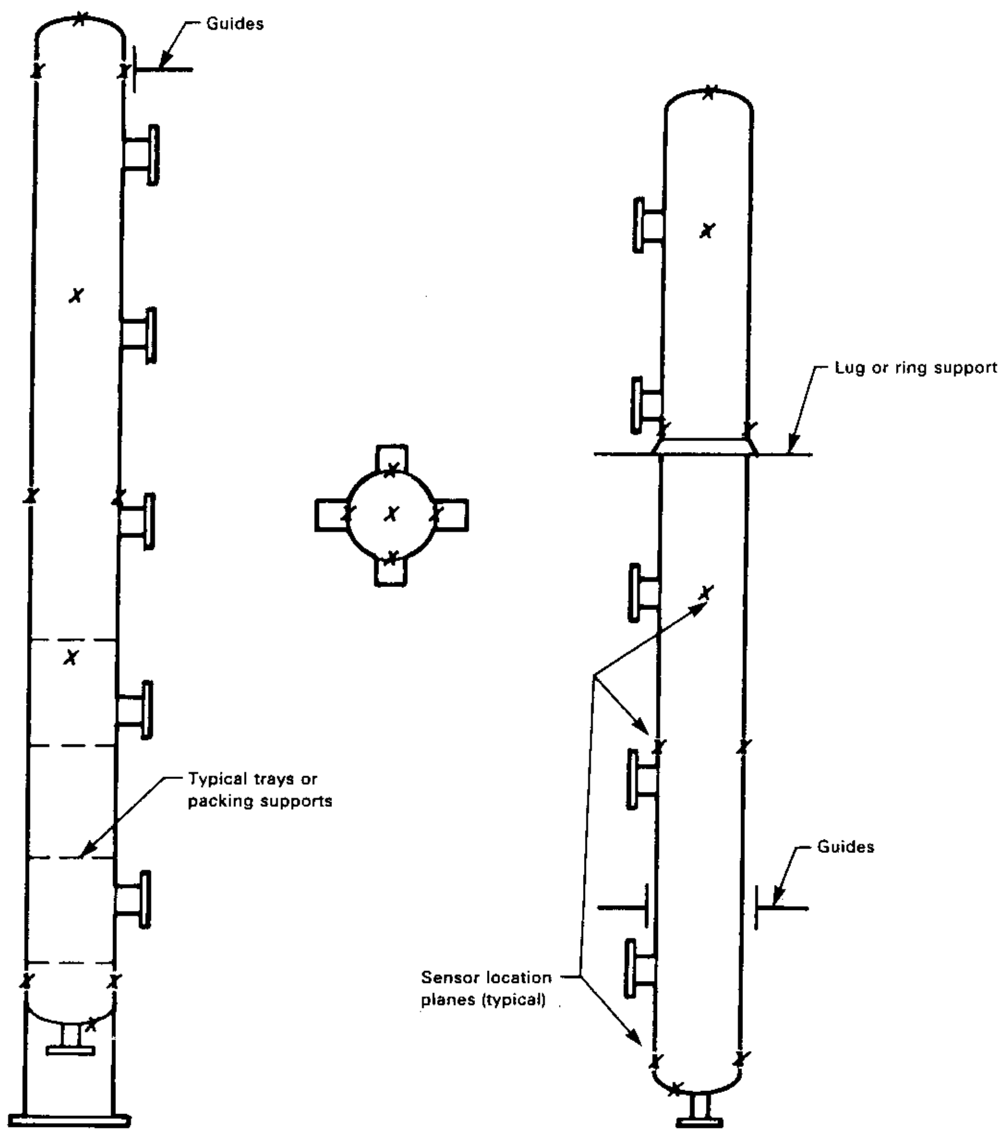
(3) Additional rows of sensors may be required.

CASE 3 — HORIZONTAL PRESSURE VESSEL DISHED HEADS, SADDLE SUPPORTED



GUIDELINES:
(1) X denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).
(2) Additional rows of sensors may be required.

CASE 4 — VERTICAL PRESSURE VESSEL PACKED OR TRAYED COLUMN DISHED HEADS, LUG OR SKIRT SUPPORTED

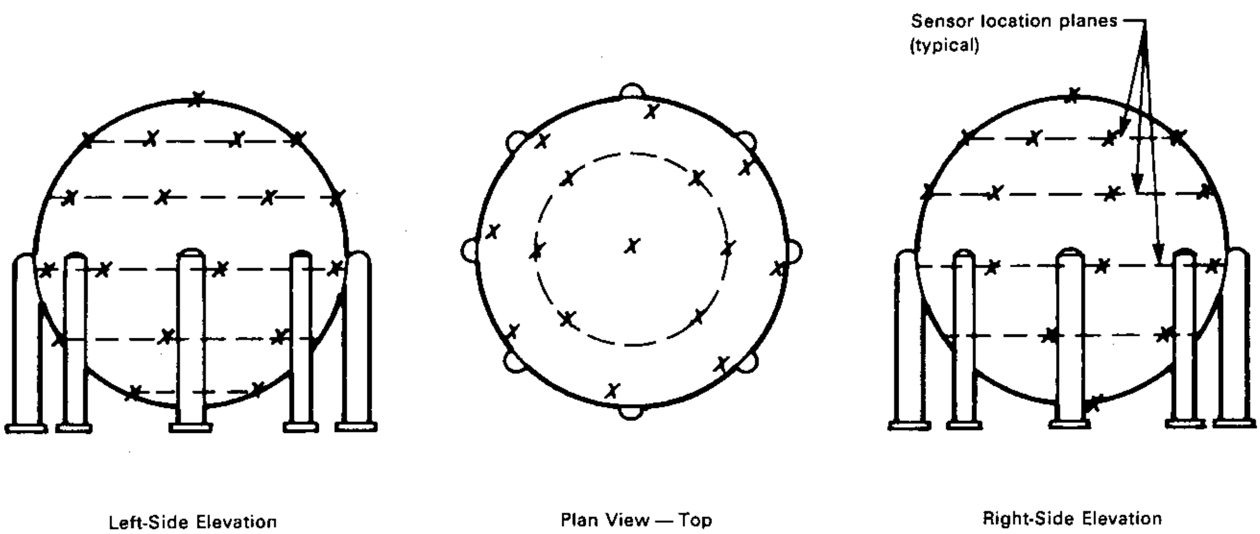


Skirt Supported

Lug or Ring Supported

GUIDELINES:
(1) X denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).
(2) Special areas may require additional sensors.
(3) Additional rows of sensors may be required.

CASE 5 — SPHERICAL PRESSURE VESSEL, LEG SUPPORTED



GUIDELINES:
(1) *X* denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).
(2) Additional sensors may be required.

APPENDIX B — SUPPLEMENTAL INFORMATION FOR CONDUCTING ACOUSTIC EMISSION EXAMINATIONS

B-10 FREQUENCY SELECTION

The frequency band of 100 kHz–200 kHz is the lowest frequency band that should be considered for general AE pressure vessel examination. Higher frequency bands may be considered if background noise cannot be eliminated. If a higher frequency band is used the following items must be considered.

(a) Attenuation characteristics will change.

(b) Sensor spacings will decrease and more sensors will be required to adequately cover the evaluation area.

(c) Instrumentation performance requirements described in Appendix I must be adjusted to the higher frequency band.

(d) Instrumentation calibration described in Appendix II must be performed at the higher frequency band.

(e) Alternate evaluation/acceptance criteria must be obtained from the referencing Code Section.

B-20 COMBINING MORE THAN ONE SENSOR IN A SINGLE CHANNEL

Two or more sensors (with preamplifiers) may be plugged into a single channel to overcome the effects of local shielding in a region of the vessel. One specific example of this is the use of several sensors (with preamplifiers around a manway or nozzle).

B-30 ATTENUATIVE WELDS

Some have been shown to be highly attenuative to non-surface waves. This situation predominantly affects multichannel source location algorithms. This situation can be identified by modifying the attenuation characterization procedure to produce a stress wave which does not contain surface waves traveling across the weld.

B-40 PRODUCTION LINE TESTING OF IDENTICAL VESSELS

For situations which involve repeated tests of identical vessels where there is no change in the essential variables such as material, thickness, product form and type, the requirement for attenuation characterization on each vessel is waived.

transverse wave — see *shear wave.*

transverse wave — wave motion in which the particle displacement at each point in a material is perpendicular to the direction of propagation (E 494)

true attenuation — that portion of the observed ultrasound energy loss which is intrinsic to the medium through which the ultrasound propagates. True attenuation losses may be attributed to the basic mechanisms of absorption and scattering. (E 664)

ultrasonic — pertaining to mechanical vibrations having a frequency greater than approximately 20,000 Hz

ultrasonic noise level — the large number of unresolved indications resulting from structure or possibly from numerous small discontinuities, or both (E 127)

ultrasonic spectroscopy — analysis of the frequency spectrum of an ultrasonic wave

vee path — the angle-beam path in materials starting at the search-unit examination surface, through the material to the reflecting surface, continuing to the examination surface in front of the search unit, and reflection back along the same path to the search unit. The path is usually shaped like the letter V.

vertical limit — the maximum readable level of vertical indications determined either by an electrical or a physical limit of an A-scan presentation

video presentation — display of the rectified, and usually filtered, r-f signal

water path — the distance from the transducer to the test surface in immersion or water column testing

wave front — a continuous surface drawn through the most forward points in a wave disturbance which have the same phase

wave train — a succession of ultrasonic waves arising from the same source, having the same characteristics, and propagating along the same path

wedge — in ultrasonic angle-beam examination by the contact method, a device used to direct ultrasonic energy into the material at an angle

wheel search unit — an ultrasonic device incorporating one or more piezoelectric elements mounted inside a liquid-filled flexible tire. The beam is coupled to the test surface through the rolling contact area of the tire.

wrap around — the display of misleading reflections from a previously transmitted pulse, caused by an excessively high pulse-repetition frequency

13. Infrared Examination (E 1213)

absorptance, α — the ratio of radiant flux absorbed by a surface to that incident upon it

apparent temperature — the temperature of an object as determined solely from the measured radiance, assuming an emissivity of unity

background radiation — all radiation received by the infrared sensing device that was not emitted by the specified area of the surface being examined

background, target — that portion of the background which is confined to the field of view

blackbody — an ideal thermal radiator (emissivity = 1.0) that emits and absorbs all of the available thermal radiation at a given temperature

blackbody equivalent temperature — the apparent temperature of an object as determined from the measured radiance and the assumption that it is an ideal blackbody with emissivity of 1.0

differential blackbody — an apparatus for establishing two parallel isothermal planar zones of different temperatures, and with effective emissivities of 1.0 (E 1213)

emissivity, ϵ — the ratio of the radiance of a body at a given temperature to the corresponding radiance of a blackbody at the same temperature

extended source — a source of infrared radiation whose image completely fills the field of view of a detector

NOTE 21 — The irradiance is independent of the distance from the source to the region of observation. In practice, sources that are not extended sources are considered to be point sources; see *point source.*

field of view (FOV) — the shape and angular dimensions of the cone or the pyramid which define the object space imaged by the system; for example, rectangular, 4 deg. wide by 3 deg. high

imaging line scanner — an apparatus that scans in a single dimension and is moved perpendicular to the scan direction to produce a two-dimensional thermogram of a scene

infrared imaging system — an apparatus that converts the two-dimensional spatial variations in infrared radiance from any object surface into a two-dimensional thermogram of the same scene, in which variations in radiance are displayed in gradations of gray tone or in color

infrared reflector — a material with a reflectance in the infrared region as close as possible to 1.00

infrared sensing device — one of a wide class of instruments used to display or record, or both, information related to the thermal radiation received from any object surfaces viewed by the instrument. The instrument varies in complexity from spot radiometers to two-dimensional real-time imaging systems.

infrared thermographer — the person qualified or trained to use infrared imaging radiometer

infrared thermography — see *thermography, infrared*

Figures

Mandatory Appendices

Figures

Tables

ARTICLE 13
CONTINUOUS ACOUSTIC EMISSION MONITORING

T-1310 SCOPE

This Article describes requirements to be used during continuous acoustic emission (AE) montioring of metal or non-metal pressure boundary components used for either nuclear or non-nuclear service. Monitoring may be performed as a function of load, pressure, temperature, and/or time.

When AE monitoring in accordance with this Article is required, the referencing Code Section should specify the following:

(a) personnel qualification/certification requirements

(b) extent of examination and/or area(s)/volume(s) to be monitored

(c) duration of monitoring period

(d) acceptance/evaluation criteria

(e) reports and records requirements

When this Article is specified by a referencing Code section, the technical requirements described herein shall be used together with Article 1, General Requirements. Definitions of terms used in this Article are in Mandatory Appendix VII of this Article.

Generic requirements for continuous acoustic emission monitoring of pressure boundary components during operation are addressed within this Article. Supplemental requirements for specific applications such as nuclear components, non-metallic components, monitoring at elevated temperatures, limited zone monitoring, lead detection, etc., are provided in the Mandatory Appendices to this Article.

T-1311 References

SE-650, Standard Guide for Mounting Piezoelectric Acoustic Emission Sensors

SE-976, Standard Guide for Determining the Reproducibility of Acoustic Emission Sensor Response

SE-1211, Standard Practice for Leak Detection and Location using Surface-Mounted Acoustic Emission Sensors

SE-1316, Standard Terminology for Nondestructive Examinations

SE-1419, Standard Test Method for Examination of Seamless, Gas-Filled Pressure Vessels Using Acoustic Emission

ASTM E 750-88 (1993), Standard Practice for Characterizing Acoustic Emission Instrumentation

ASTM E 1067-89 (1991), Standard Practice for Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin (FRP) Tanks/Vessels

ASTM E 1118-89, Standard Practice for Acoustic Emission Examination of Reinforced Thermosetting Resin Pipe (RTRP)

ASTM E 1139-92, Standard Practice for Continuous Monitoring of Acoustic Emission from Metal Pressure Boundaries

T-1320 GENERAL

T-1321 Monitoring Objectives

The objectives of AE examination are to detect, locate, and characterize AE sources, and interpret the AE response signals to evaluate significance relative to pressure boundary integrity. These AE sources are limited to those activated during normal plant system operation, i.e., no special stimulus is applied exclusively to produce AE. In the context of this Article, normal system operation may include routine pressure tests performed during plant system shutdown.

T-1322 Relevant Indications

All relevant indications detected during AE monitoring should be evaluated by other methods of nondestructive examination.

T-1323 Personnel Qualification

T-1323.1 Procedures and Equipment Installation. All procedures used for qualifying, calibrating, installing, and operating the AE equipment, and for data analysis activities, shall be approved by a certified AE Level III.

Installation, calibration, and checkout of the AE equipment shall be performed under the direction of a certified AE Level III.

T-1323.2 AE System Operation. Routing operation of the AE system for collection and interpretation of data may be performed by competent personnel that are not necessarily AE specialists. However, AE system operation and data interpretation shall be verified by a certified AE Level III on approximately monthly intervals or more often if the system appears to be malfunctioning, relevant signals are detected, or an abrupt change in the rate of AE signals is observed.

T-1324 Component Stressing

Several means of stressing are applicable to AE examination including startup, continuous and cyclic operation, and shut-down of operating plant systems and components, as well as pressure tests of non-operating plant systems. Stress may be induced by either pressure or thermal gradients or a combination of both. It is the intent of this Article to describe examination techniques that are applicable during normal operation of pressurized plant system or component. During startup, the pressurizing rate should be sufficient to facilitate the examination with minimum extraneous noise. If appropriate, provisions should be made for maintaining the pressure at designated hold points. Advice on the use of compressed gas as a pressurizing medium is contained in SE-1419.

T-1325 Noise Interference

Noise sources that interfere with AE signal detection should be controlled to the extent possible. For continuous monitoring, it may be necessary to accommodate background noise by monitoring at high frequencies, shielding open AE system leads, using differential sensors, and using special data filtering techniques to reduce noise interference.

T-1326 Coordination With Plant System Owner/Operator

Due to operational considerations unique to the AE method, close coordination between the AE monitor operator and the owner/operator of the plant should be established and maintained. Provisions for this coordination function should be described in the written procedures submited for approval prior to initiation of AE monitoring activities.

T-1327 Source Location and Sensor Mounting

Sources shall be located with the specified accuracy by multichannel sensor array, zone location, or both. As required by the referencing Code section, requirements for sensor mounting, placement, and spacing are further defined in the applicable Appendix.

T-1330 EQUIPMENT

T-1331 General

The AE system will consist of sensors, preamplifiers, amplifiers, filters, signal processors, and a data storage device together with interconnecting cables. Simulated AE source(s) and auxiliary equipment such as pressure and temperature inputs are also required. The AE monitoring system shall provide the functional capabilities shown in Fig. T-1331.

T-1332 Sensors

Sensors shall be one of two general types — those mounted directly on the surface of the component being monitored and those that are separated from the surface of the component by a connecting waveguide. Sensors shall be acoustically coupled to the surface of the component being monitored and be arranged in arrays capable of providing AE signal detection and source location to the required accuracy. Selection of sensor type shall be based on the application; i.e., low or high temperature, nuclear or non-nuclear, etc. The sensor selected for a specific application shall be identified in the procedure prepared for that application. The sensor system (i.e., sensors, preamplifiers, and connecting cables) used to detect AE shall limit electromagnetic interference to a level not exceeding 0.7 V peak after 90 dB amplification.

T-1332.1 Sensor Response Frequency. For each application, selection of the sensor response frequency shall be based on a characterization of background noise in terms of amplitude vs. frequency. The lowest frequency compatible with avoiding interference from background noise should be used to maximize sensitivity of AE signals and minimize signal attenuation.

T-1332.2 Differential and Tuned Sensors. Two sensor designs have been effective in overcoming noise interference problems. One is a differential sensor that operates to cancel out electrical transients entering the system through the sensor. The other is an inductively tuned sensor that operates to shape the sensor response around a selected frequency; i.e., inductive tuning allows

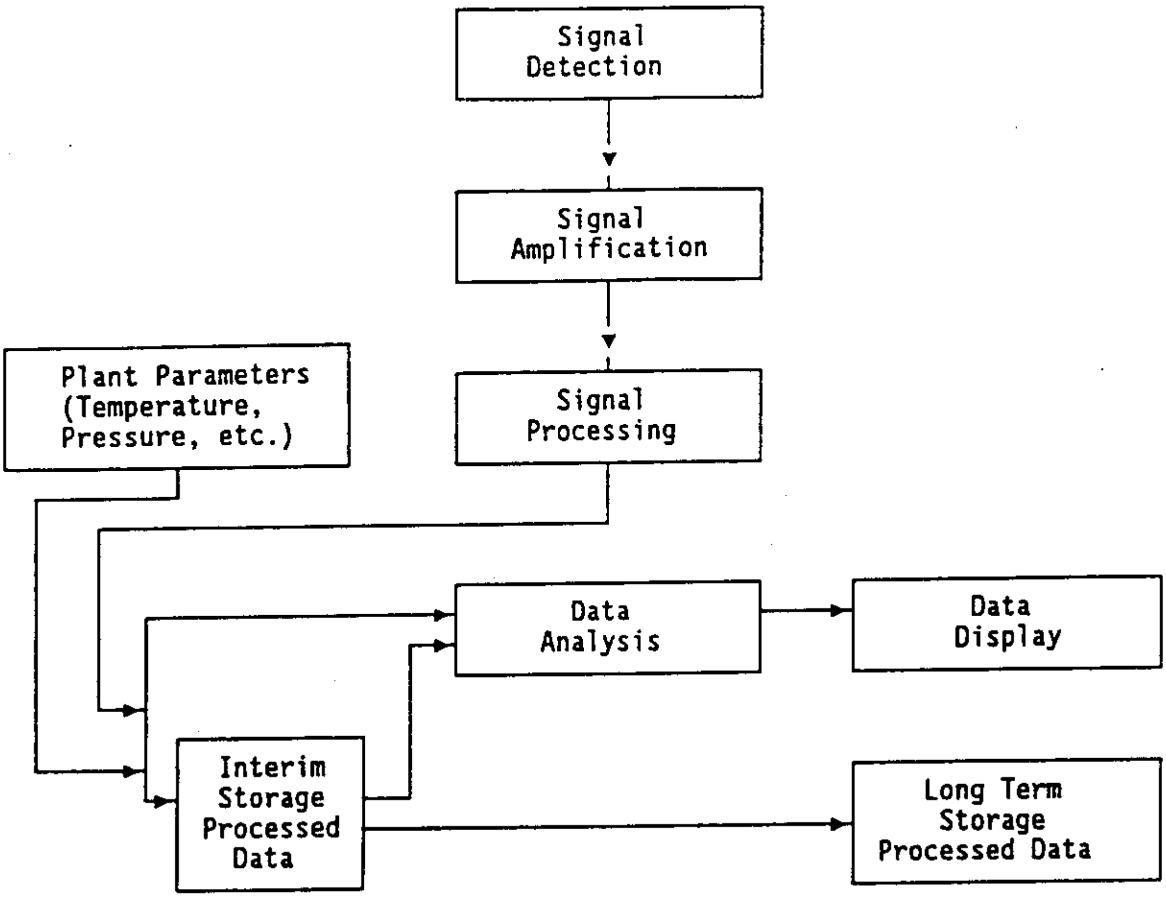


FIG. T-1331 FUNCTIONAL FLOW DIAGRAM — CONTINUOUS AE MONITORING SYSTEM

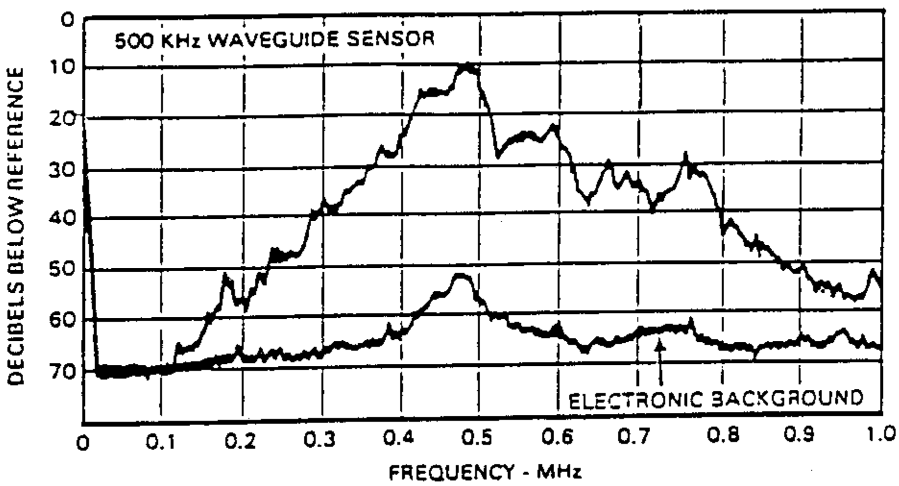


FIG. T-1332.2 RESPONSE OF A WAVEGUIDE AE SENSOR INDUCTIVELY TUNED TO 500 kHz

discrimination against frequencies on either side of a selected response frequency as shown in Fig. T-1332.2. These sensor designs may be used separately or together.

T-1332.3 Sensor Mounting. Sensors shall be mounted to the component surface using two basic methods. One is to bond the sensor directly to the surface with an adhesive. Temperature and vibration can adversely affect the bond between the sensor and the surface being monitored. Also, the chemical content of the adhesive shall be checked to assure that it is not deleterious to the surface of the component.

The second method for mounting a sensor employs pressure coupling using either a strap or a magnetic mount. A thin, soft metal interface layer between the sensor and the surface is often effective for achieving acoustic coupling with minimal pressure. In the case of waveguide sensors, the tip of the waveguide may be shaped to reduce the required force to maintain acoustic coupling.

T-1333 Signal Cables

Coaxial cables shall be used to conduct the AE signals from the sensors to the monitoring instrument (monitor). Whenever a protective barrier or containment structure must be penetrated using a bulkhead fitting or penetration plug to transmit signals from the sensor to the monitor, extreme care must be taken to avoid incurring excessive signal loss or noise. When the coaxial (signal) cables are used to supply DC power to the preamplifiers/line drivers, they should be terminated with the appropriate characteristic impedance.

T-1334 Amplifiers

At least one preamplifier shall be used with each sensor to amplify the AE signals for transmission to the monitor. Where long signal cables are required, a preamplifier and line driver between the sensor and the monitor may be needed.

With the high signal amplification required to detect AE signals, the internal noise of the preamplifiers must be minimized to avoid interference with AE signal detection. The frequency response band of the amplifiers shall be matched to the response profile determined for the AE sensors.

T-1335 AE Monitor

The AE monitor shall include a post amplifier, a signal identification function, and a signal processing module for each signal channel. The monitor shall also include a video display function that can be used at the operator's discretion to display AE data as well as a data storage capability suitable for long term, nonvolatile data storage. A data analysis function may be integral with the AE monitor or be a separate function that draws from the stored AE data.

The post amplifier shall meet the requirements of T-1334. The AE monitor shall be capable of processing and recording incoming data at a rate of at least 50 hits/sec for all channels simultaneously for an indefinite time period and at a rate of at least 100 hits/sec for all channels simultaneously for any 15 sec period.

T-1335.1 AE Signal Identification. A real-time signal discrimination function to process incoming signals and identify relevant AE signals shall be included. The discrimination function may either exclude all signals not identified as AE from crack growth, or flag those signals identified as crack growth AE while accepting all signals above the voltage threshold.

T-1335.2 Signal Processing. The dynamic range of the signal processor shall be at least 36 dB for each parameter being measured. The signal processor shall be controlled by voltage threshold circuits that limit accepted data to signals that exceed the voltage amplitude threshold. The voltage threshold shall be determined on the basis of the background noise.

Signal parameters to be measured shall include AE hit count, total number of signal hits at each sensor, signal peak amplitude, time for threshold crossing to signal peak, measured area under the rectified signal envelope (MARSE) in V-secs, and difference in time of signal arrival (δt) at all sensors in a sensor array used for AE source location. In addition to the AE signal features above, clock time, date, and the value of plant parameters (internal pressure, temperature, etc., that can be identified as significant to crack growth) associated with the time of signal detection shall be recorded for each signal. The signal processor section shall also measure the overall RMS background signal level for each sensing channel for leak detection purposes.

T-1335.3 Data Storage. Data storage shall be nonvolatile and capable of storing the data described in T-1335.2 continuously over time periods of several weeks to several months depending on the application. One recording method that has proven satisfactory for continuous monitoring is a digital tape recorder using $\frac{1}{4}$ in. (6 mm), 16 track digital tape cartridges.

T-1335.4 Data Analysis and Display. The data analysis function of the AE monitor shall determine the location of AE sources as specified in the procedure

(T-1350). Location accuracies within one wall thickness of the pressure boundary or 5% of the minimum sensor spacing, whichever is greater, are typical for metal components.

The data anaylsis function shall be capable of providing a display and plot of selected AE information (e.g., AE events, crack growth AE from a given source area, AE energy) vs. plant system parameters and vs. time for correlation evaluations. Data analysis shall also provide continuous assessment of RMS signal level information derived from the signal measurement section.

The AE monitor system shall provide a means of presenting analyzed data; either a computer printout or a printout in conjunction with a video display. When the AE rate from an array exceeds the rate specified in the written procedure, the system shall activate an operator alert and identify the sensor array producing the high AE rate.

T-1340 REQUIREMENTS

T-1341 Equipment Qualification

Acceptable performance, including dynamic range, of the complete AE monitor (without sensors) shall be verified using an electronic waveform generator prior to installation. Sinusoidal burst signals from the waveform generator shall be input of each preamplifier to verify that the signal amplification, data processing functions, data processing rate, and data analysis, display, and storage meet the requirements of this Article. (NOTE: AE signal source location performance is tested under T-1362.1.) With the AE monitor gain set at operating level, the system shall be evaluated using input signals that will test both the low and high ends of the dynamic range of the AE monitor system. Signal frequencies shall include samples within the range of intended use.

T-1342 Sensor Qualification

T-1342.1 Sensor Sensitivity and Frequency Response. Each sensor shall produce a minimum signal of 0.1 mV_{peak} referred to the sensor output at the selected monitoring frequency when mounted on a calibration block and excited with a helium gas jet as described in SE-976. Appropriate calibration blocks are identified in the Appendices as a function of specific applications. Helium gas excitation shall be performed using a 30 psi (207 KPa) helium source directed onto the surface of the calibration block through a #18 hypodermic needle held perpendicular to the calibration block surface. The needle tip shall be $\frac{1}{8}$ in. (3.2 mm) above the surface of the block and $1\frac{1}{2}$ in. (38 mm) from the mounted sensor. The process may also be used to verify the sensor response profile in terms of frequency to assure that the response roll-off on either side of the selected monitoring frequency is acceptable.

An optional technique for determining the reproducibility of AE sensor response is referred to as the "Pencil Lead Break" technique, which is described in SE-976.

T-1342.2 Uniformity of Sensor Sensitivity. The sensitivity of each sensor shall be evaluated by mounting it on a calibration block as it will be mounted on the plant component and measuring its response to the energy produced by fracturing a 0.3-mm, 2H pencil lead against the surface of the block in accordance with SE-976 at a point 4 in. (102 mm) from the center of the sensor. When performing this evaluation, it is useful to use a 40 dB preamplifier with the sensor to produce and adequate output signal for accurate measurement. The peak response of each sensor to the simulated AE signal shall not vary more than 3 dB from the average for all sensors at the selected monitoring frequency.

T-1343 Signal Pattern Recognition

If AE signal pattern recognition is used, this function shall be demonstrated and qualified as follows:

(a) Assemble the AE monitor including two representative sensors mounted on a calibration block with the same acoustic coupling process to be used for monitoring. The sensors shall be excited ten times by each of the following three methods:

(1) Fracture a 0.3 mm, 2H pencil lead against the surface of the block in accordance with SE-976.

(2) Strike the surface of the block with 0.25 in. (6 mm) diameter steel ball dropped from a uniform height sufficient to produce a response from the sensors that does not saturate the AE monitor.

(3) Inject a multi-cycle (five cycles minimum) burst signal into the block with a transducer and waveform generator.

(b) The pattern recognition function shall identify at least 8 out of 10 lead fracture signals as AE crack growth signals and at least 8 out 10 of each other type signals as signals not associated with crack growth.

T-1344 Material Attenuation/Characterization

Prior to installation of AE system for monitoring plant components, the acoustic signal attenuation in the material shall be characterized. This is necessary for

determining the sensor spacing for effective AE detection. Attenuation measurements shall be made at the frequency selected for AE monitoring and shall include both surface and bulk wave propagation. The attenuation measurements should be performed with the material temperature within ± 200°F (±111°C) of the expected temperature during actual component monitoring.

T-1345 Background Noise

The AE system response to background noise shall be characterized. With 90 dB amplification, the AE system signal level response to continuous process background noise shall not exceed 1.5 V_{peak} output. This shall be achieved by restricting the frequency response of the sensor system. Reducing sensitivity is not acceptable.

T-1346 Qualification Records

Documentation of the equipment qualification process shall include the following:

(a) a copy of the equipment qualification procedure

(b) personnel certificate records

(c) description of the AE equipment and qualification equipment used

(d) quantitative results of the qualification

(e) signature of the AE Level III responsible for the qualification

(f) date of the qualification

Equipment qualification records shall be retained as part of the monitoring application records.

T-1347 Sensor Installation

T-1347.1 Coupling. Adequate acoustic coupling between the sensor and the component surface shall be verified as the sensors are mounted. This can be done by lightly tapping the surface or by breaking a pencil lead against the component surface while observing the sensor output. Guidance for sensor mounting is provided in SE-650 and in T-1332.3. The use of drilled and tapped holes in the component is generally not acceptable.

T-1347.2 Array Spacing. A sufficient number of sensors shall be located on the component in a multisource array(s) to provide for AE signal detection and source location. Each sensor shall produce an output of at least 0.3 mV_{peak} when a 0.3 mm, 2H pencil lead is broken against the bare surface of the component at the most remote location that the sensor is expected to monitor. When a location algorithm is used, the location of each lead break shall be surrounded with a material (mastic or putty) to absorb surface waves. A 0.1 in. (2.5 mm) lead extension shall be broken at an angle of approximately 30 deg. to the component surface.

T-1347.3 Functional Verification. One or more acoustic signal sources, with an output frequency range of 100 to 700 kHz shall be installed within the monitoring zone of each sensor array for the purpose of periodically testing the functional integrity of the sensors during monitoring. This is not intended to provide a precise sensor calibration but rather a qualitative sensitivity check. It shall be possible to activate the acoustic signal source(s) from the AE monitor location.

T-1348 Signal Lead Installation

The coaxial cable and other leads used to connect the sensors to the AE monitor shall be demonstrated to be capable of withstanding extended exposure to hostile environments as required to perform the monitoring activities.

T-1349 AE Monitor Installation

The AE monitor shall be located in a clean, controlled environment suitable for long-term operation of a computer system. The electronic instrumentation (preamplifiers and AE monitor components) shall be located in an area that is maintained at temperatures not exceeding 125°F.

T-1350 PROCEDURE REQUIREMENTS 01

AE monitoring activities shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable:

(a) Components to be monitored include dimension, materials of construction, operating environment, and duration of monitoring

(b) a description of the AE system to be used and its capabilities in terms of the functional requirements for the intended application

(c) AE system calibration and qualification requirements

(d) number, location, and mounting requirements for AE sensors

(e) interval and acceptable performance during the AE system functional check (T-1373.2)

(f) data recording processes and data to be recorded

(*g*) data analysis, interpretation, and evaluation criteria

(*h*) supplemental NDE requirements

(*i*) personnel qualification/certification requirements

(*j*) reporting and record retention requirements

The procedure described below need not be large documents, and preprinted blank forms (technique sheets) may be utilized provided they contain the required information.

T-1351 AE System Operation

A written precedure describing operation of the AE system shall be prepared, approved by the cognizant AE Level III, and made available to the personnel responsible for operating the AE system. Each procedure shall be tailored to recognize and accommodate unique requirements associated with the plant system or component being monitored.

T-1352 Data Processing, Interpretation, and Evaluation

A written procedure for processing, interpreting, and evaluating the AE data shall be prepared and approved by the cognizant AE Level III. This procedure shall be made available to the personnel responsible for operating the AE system, the personnel responsible for AE data interpretation and evaluation, and a representative of the owner of the plant system being monitored. This procedure shall be tailored to recognize and accommodate unique requirements associated with the plant system or component being monitored.

T-1353 Data Recording and Storage

Specific requirements for recording, retention, and storage of the AE and other pertinent data shall be prepared for approval by representatives of the plant system owner or operator. These requirements shall be made available to the personnel responsible for data recording and storage.

T-1360 CALIBRATION

T-1361 Sensors

The frequency response for each AE channel shall be measured with the sensors installed on a plant pressure boundary component. Sensor response shall be measured at the output of the preamplifier using a spectrum analyzer. The excitation source shall be a helium gas jet directed onto the component surface from a nominal 30 psi (207 kPa) source through a #18 hypodermic needle held perpendicular to the component surface at a stand-off distance of $\frac{1}{8}$ in. (3.2 mm) located $1\frac{1}{2}$ in. (38 mm) from the mounted sensor. The gas shall not impinge on the sensor or the waveguide. AE sensor peak response to the gas jet excitation at the monitoring frequency shall be at least 0.1 mV_{peak} referred to the output of the sensor. Any AE sensor showing less than 0.1 mV_{peak} output shall be reinstalled or replaced, as necessary, to achieve the required sensitivity.

An optional technique for determining the reproducibility of AE sensor response is referred to as the "Pencil Lead Break" technique which is described in SE-976.

T-1362 Complete AE Monitor System

T-1362.1 Detection and Source Location. The signal detection and source location accuracy for each sensor array shall be measured using simulated AE signals injected on the component surface at not less than 10 preselected points within the array monitoring field. These simulated AE signals shall be generated by breaking 2H pencil leads (0.3 or 0.5 mm diameter) against the component surface at the prescribed points. The pencil leads shall be broken at an angle of approximately 30 deg. to the surface using a 0.1 in. (2.5 mm) pencil lead extension (see SE-976). The location of each pencil lead break shall be surrounded with a material (mastic or putty) to absorb surface waves. Location accuracies within one wall thickness at the AE source location or 5% of the minimum sensor array spacing distance, whichever is greater, are typical.

T-1362.2 Function Verification. Response of the AE system to the acoustic signal source described in T-1347.3 shall be measured and recorded for reference during later checks of the AE system.

T-1363 Calibration Intervals

The installed AE monitor system shall be recalibrated in accordance with T-1360 at the end of each plant operating cycle. This is defined more explicitly in the Appendices describing requirements for each AE monitoring application.

T-1364 Calibration Records

Documentation of the installed system calibration shall include the following:

(a) a copy of the calibration procedure(s)

(b) personnel certification records

(c) description of the AE equipment and the calibration equipment used

(d) quantitative results of the calibration

(e) signature of the individual responsible for the calibration

(f) date(s) of the calibration(s).

Retention of the calibration records shall be in accordance with T-1393.

T-1370 EXAMINATION

The AE monitor system shall comply with the requirements of approved procedures (T-1350) that have been accepted by the plant owner/operator.

T-1371 Personnel

Operation of the AE system for routine collection and interpretation of data may be performed by a competent individual not necessarily specialized in AE who has received training and has at least limited AE Level II certification. However, AE system operation and data interpretation shall be verified by a certified AE Level III on a monthly interval or sooner if the system appears to be malfunctioning or there is an abrupt change in the rate of AE data accumulation.

T-1372 Plant Startup

During plant startup, AE rate and source location information shall be evaluated at least once per shift for indications of flaw growth. The RMS signal level shall also be evaluated for indications of pressure boundary leaks.

T-1373 Plant Steady-State Operation

T-1373.1 Data Evaluation Interval

AE data shall be evaluated at least weekly during normal plant operation. When a sustained AE activity rate from one or more sensors occurs or when a consistent clustering of AE signals accepted by the signal identification analyzer and which cluster in one source location of AE signals is concentrated within a diameter of three times the wall thickness of the component or 10% of the minimum sensor spacing distance in the array, whichever is greater. Also refer to Appendices II and III.

T-1373.2 AE System Functional Check. AE system response to the installed acoustic signal source shall be evaluated periodically as specified in the procedure. Deterioration of sensitivity exceeding 4 dB for any channel shall be recorded and the affected component shall be replaced at the earliest opportunity.

T-1374 Nuclear Components

Specific and supplemental examination requirements for nuclear components are specified in Appendix I.

T-1375 Non-Nuclear Metal Components

Specific and supplemental examination requirements for non-nuclear metal components are specified in Appendix II.

T-1376 Non-Metallic Components

Specific and supplemental examination for non-metallic components are specified in Appendix III.

T-1377 Limited Zone Monitoring

Specific and supplemental examination requirements for limited zone monitoring are specified in Appendix IV.

T-1378 Hostile Environment Applications

Specific and supplemental examination requirements for hostile environment applications are specified in Appendix V.

T-1379 Leak Detection Applications

Specific and supplemental examination requirements for leak detection applications are specified in Appendix VI.

T-1380 EVALUATION/RESULTS

T-1381 Data Processing, Interpretation, and Evaluation

Data processing, interpretation, and evaluation shall be in accordance with the written procedure (T-1350) for that specific application and the applicable Mandatory Appendices. The methodology and criteria will vary substantially with different applications.

T-1382 Data Requirements

The following data shall be acquired and recorded:

(a) AE event count versus time for each monitoring array.

(b) AE source and/or zone location for all acoustic signals accepted.

(c) AE hit rate for each AE source location cluster.

(d) Relevant AE signal parameter(s) versus time for each data channel.

(e) Location monitored, date, and time period of monitoring.

(f) Identification of personnel performing the analysis.

In addition, the data records shall include any other information required in the applicable procedure (T-1350).

T-1390 REPORTS/RECORDS

T-1391 Reports to Plant System Owner/Operator

T-1391.1 A summary of AE monitoring results shall be prepared monthly. This should be a brief, concise report for management use.

T-1391.2 Reporting requirements in the event of unusual AE indications shall be specified by the plant system owner/operator and identified in the procedure (T-1350).

T-1391.3 A summary report on the correlation of monitoring data with the evaluation criteria shall be provided to the plant system owner/operator.

T-1391.4 Upon completion of each major phase of the monitoring effort, a comprehensive report shall be prepared. This report shall include the following:

(a) complete identification of the plant system/component being monitored including material type(s), method(s) of fabrication, manufacturer's name(s), and certificate number(s)

(b) sketch or manufacturer's drawing with component dimensions and sensor locations

(c) plant system operating conditions including pressurizing fluid, temperature, pressure level, etc.

(d) AE monitoring environment including temperature, radiation and corrosive fumes if appropriate, sensor accessibility, background noise level, and protective barrier penetrations utilized, if any

(e) a sketch or manufacturer's drawing showing the location of any zone in which the AE response exceeded the evaluation criteria

(f) any unusual events or observations during monitoring

(g) monitoring schedule including identification of any AE system downtime during this time period

(h) names and qualifications of the AE equipment operators

(i) complete description of the AE instrumentation including manufacturer's name, model number, sensor types, instrument settings, calibration data, etc.

T-1392 Records

T-1392.1 Administrative Records. The administrative records for each AE monitoring application shall include the applicable test plan(s), procedure(s), operating instructions, evaluation criteria, and other relevant information, as applicable.

T-1392.2 Equipment Qualification and Calibration Data. The pre-installation and post-installation AE system qualification and calibration records including signal attenuation data and AE system performance verification checks shall be retained. Disposition of these records following AE system recalibration shall be specified by the plant system owner/operator.

T-1392.3 Raw and Processed AE Data. The raw data records shall be retained at least until the AE indications have been independently verified. The retention period for the processed data records shall be as specified in the procedure (T-1350).

T-1393 Record Retention Requirements

All AE records shall be maintained as required by the referencing Code section and the procedure (T-1350).

ARTICLE 13
MANDATORY APPENDICES

APPENDIX I — NUCLEAR COMPONENTS

I-1310 SCOPE

This Appendix specifies supplemental requirements for continuous AE monitoring of metallic components in nuclear plant systems. The requirements of Appendix V — Hostile Environment Applications shall also apply to continuous AE monitoring of nuclear plant systems.

I-1320 TERMS SPECIFIC TO THIS APPENDIX

See Appendix VII for definitions of terms specific to this Appendix.

I-1330 EQUIPMENT QUALIFICATION

I-1331 Preamplifiers

The internal electronic noise of the preamplifiers shall not exceed 7 microvolts rms referred to the input with a 50-ohm input termination. The frequency response band of the amplitude shall be matched to the response profile determined for the AE sensors.

I-1332 Monitor System

Acceptable performance, including dynamic range, of the complete AE monitor (without sensors) shall be verified using an electronic waveform generator prior to installation. Sinusoidal burst signals from the waveform generator shall be input to each preamplifier to verify that the signal amplification; data processing functions; data processing rate; and data analysis, display, and storage meet the requirements of this Article. (NOTE: AE signal source location performance is tested under T-1362.1.) The system shall be evaluated using input signals of 0.5 and 10.0 mV peak-to-peak amplitude; 0.5 and 3.0 millisecond duration; and 100 kHz, and 1.0 MHz frequency from the waveform generator.

I-1340 SENSORS

I-1341 Sensor Type

The AE sensors shall be capable of withstanding the ambient service environment (i.e., temperature, moisture, vibration, and nuclear radiation) for a period of two years. Refer to T-1332 and Appendix V, para. V-1320, for additional sensor requirements. In monitoring nuclear components, in addition to high temperature [≈600°F (316°C) in most locations], the environment at the surface of the component may also include gamma and neutron radiation. In view of the neutron radiation, a waveguide high temperature AE sensor such as the type described in Appendix V should be used to isolate the critical elements of the sensor (piezoelectric crystal and associated preamplifier) from the neutron radiation field.

I-1342 Frequency Response

The frequency response band of the sensor/amplifier combination shall be limited to avoid interference from background noise such as is caused by coolant flow. Background noise at the locations to be monitored shall be characterized in terms of intensity versus frequency prior to selection of the AE sensors to be used. This information shall be used to select the appropriate frequency bandwidth for AE monitoring. The sensor response roll off below the selected monitoring frequency shall be at a minimum rate of 15 dB per 100 kHz, and may be achieved by inductive tuning of the sensor/preamplifier combination. The high end of the frequency response band should roll off above 1 MHz at a minimum rate of 15 dB per octave to help reduce amplifier noise. These measurements shall be made using the helium gas jet technique described in T-1342.1 and T-1361.

I-1343 Signal Processing

The threshold for all sensor channels shall be set at 0.5 to 1.0 V_{peak} above the sensor channel background noise level and all channels shall be set the same.

I-1350 CALIBRATION

I-1351 Calibration Block

The calibration block used to qualify AE sensors shall be a steel block with minimum dimensions of 4 × 12 × 12 in. (101.6 × 304.8 × 304.8 mm) with the sensor mounted in the center of a major face using the acoustic coupling technique to be applied during in-service monitoring.

I-1352 Calibration Interval

The installed AE monitor system shall be recalibrated in accordance with T-1360 during each refueling or maintenance outage, but no oftener than once every 24 months.

I-1360 EVALUATION/RESULTS

(a) The monitoring procedure (T-1350) shall specify the acceptance criteria for crack growth rate.

(b) The AE data shall be evaluated based on AE rate derived from signals accepted by the signal identification function and identified with a specific area of the pressure boundary.

(c) The data shall be analyzed to identify an increasing AE rate that is indicative of accelerating crack growth.

(d) The quantitative crack growth rate shall be estimated using the relationship:

$$\frac{da}{dt} = 290 \left(\frac{dN}{dt}\right)^{0.53}$$

where

da/dt = crack growth rate in microinches/second

dN/dt = the AE rate [AE as defined in (b) above] in events/second

(e) If the estimated crack growth rate exceeds the acceptance criteria, the flaw area shall be examined with other NDE methods at the earliest opportunity.

APPENDIX II — NON-NUCLEAR METAL COMPONENTS

II-1310 SCOPE

This Appendix specifies supplemental requirements for continuous AE monitoring of non-nuclear metal components. The principal objective is to monitor/detect acoustic emission (AE) sources caused by surface and internal discontinuities in a vessel wall, welds, and fabricated parts and components.

II-1320 EQUIPMENT/QUALIFICATIONS

II-1321 Sensor Response

Acoustic emission sensors shall have a resonant response between 100 kHz to 400 kHz. Minimum sensitivity shall be −85 dB referred to 1 volt/microbar determined by a face-to-face ultrasonic test. Sensors shall have a frequency response with variations not exceeding 4 dB from the peak response. Acoustic emission sensors in a face-to-face ultrasonic test (or equivalent) shall not vary in peak sensitivity by more than 3 dB from when they were new.

II-1322 Couplant

Couplant shall provide consistent coupling efficiency for the duration of the test.

II-1323 Preamplifier

The preamplifier shall be located within 6 ft (1.8 m) from the sensor, and differential preamplifiers shall have 40 dB of common-mode noise rejection. Frequency response shall not vary more than 3 dB over the operating frequency range of the sensors when attached. Filters shall be of the band pass or high pass type and shall provide a minimum of 24 dB of common-mode rejection.

II-1324 Signal Cable

Power signal cable shall be shielded against electromagnetic noise. Signal loss shall be less than 1 dB per foot of cable length. Recommended maximum cable length is 500 ft (152 m).

II-1325 Power Supply

A stable, grounded electrical power supply should be used.

II-1326 Main Amplifier

The main amplifier gain shall be within 3 dB over the range of 40°F to 125°F (4°C to 52°C).

II-1327 Main Processor

The main processor(s) shall have circuits for processing sensor data. The main processor circuits shall be capable of processing hits, counts, peak amplitudes, and MARSE on each channel, and measure the following:

(a) Threshold. The AE instrument shall have a threshold control accurate to within ±1 dB over its useful range.

(b) Counts. The AE counter circuit shall detect counts over a set threshold with an accuracy of ±5%.

(c) Hits. The AE instrument shall be capable of measuring, recording, and displaying a minimum of 20 hits/sec total for all channels.

(d) Peak Amplitude. The AE circuit shall measure peak amplitude with an accuracy of ±2 dB. Useable dynamic range shall be a minimum of 60 dB with 1 dB resolution over the frequency bandwidth used. Not more than 2 dB variation in peak detection accuracy shall be allowed over the stated temperature range. Amplitude values shall be specified in dB and must be referenced to a fixed gain output of the system (sensor or preamplifier).

(e) Energy. The AE circuit shall measure MARSE with an accuracy of ±5%. The useable dynamic range for energy shall be a minimum of 40 dB.

(f) Parametric Voltage. If parametric voltage is measured, it shall be measured to an accuracy of ±2% of full scale.

II-1330 SENSORS

II-1331 Sensor Mounting/Spacing

Sensor location and spacing shall be based on attenuation characterization, with the test fluid in the vessel, and a simulated source of AE. Section V, Article 12, Nonmandatory Appendices should be referenced for vessel sensor placement. Consideration should be given to the possible attenuation effects of welds.

II-1332 Sensor Spacing for Multichannel Source Location

Sensors shall be located such that a lead break at any location within the examination area is detectable by at least the minimum number of sensors required for the multichannel source location algorithm, with the measured amplitude specified by the referencing Code Section. Location accuracy shall be within a miximum of 2 wall thicknesses or 5% of the sensor spacing distance, whichever is greater.

II-1333 Sensor Spacing for Zone Location

When zone location is used, sensors shall be located such that a lead break at any location within the examination area is detectable by at least one sensor with a measured amplitude not less than specified by the referencing Code Section. The maximum sensor spacing shall be no greater than one-half the threshold distance. The threshold distance is defined as the distance from a sensor at which a pencil-lead break on the vessel produces a measured amplitude equal to the evaluation threshold.

II-1340 CALIBRATION

II-1341 Manufacturer's Calibration

Purchased AE system components shall be accompanied by manufacturer's certification of performance specifications and tolerances.

II-1342 Annual Calibration

The instrumentation shall have an annual, comprehensive calibration following the guideline provided by the manufacturer using calibration instrumentation meeting the requirements of a recognized national standard.

II-1343 System Performance Check

Prior to beginning the monitoring period, the AE instrument shall be checked by inserting a simulated AE signal at each main amplifier input. The device generating the simulated signal shall input a sinusoidal burst-type signal of measurable amplitude, duration, and carrier frequency. On-site system calibration shall verify system operation for threshold, counts, MARSE, and peak amplitude. Calibration values shall be within the range of values specified in II-1327.

II-1344 System Performance Check Verification

Verification of sensor coupling and circuit continuity shall be performed following sensor mounting and system hookup and again following the test. The peak amplitude response of each sensor to a repeatable simulated AE source at a specific distance from the sensor should be taken prior to and following the monitoring period. The measured peak amplitude should not vary more than ±4 dB from the average of all the sensors. Any channel failing this check should be

TABLE II-1351
AN EXAMPLE OF EVALUATION CRITERIA FOR ZONE LOCATION

	Pressure Vessels (Other Than First Hydrostatic Test) Using Zone Location
Emissions during hold	Not more than *E* hits beyond time *T*
Count rate	Less than *N* counts per sensor for a specified load increase
Number of hits	Not more than *E* hits above a specified amplitude
Large amplitude	Not more than *E* hits above a specified amplitude
MARSE or aplitude	MARSE or amplitudes do not increase with increasing load
Activity	Activity does not increase with increasing load
Evaluation threshold, dB	50 dB

repaired or replaced, as necessary. The procedure will indicate the frequency of system performance checks.

II-1350 EVALUATION

II-1351 Evaluation Criteria — Zone Location

All data from all sensors shall be used for evaluating indications. The AE criteria shown in Table II-1351 provide one basis for assessing the significance of AE indications. These criteria are based on a specific set of AE monitoring conditions. The criteria used for each application shall be as specified in the referencing Code Section and the AE procedure (see T-1350).

II-1352 Evaluation Criteria — Multisource Location

All data from all sensors shall be used for evaluating indications. The AE criteria shown in Table II-1352 provide one basis for assessing the significance of AE indications. These criteria are based on a specific set of AE monitoring conditions. The criteria used for each application shall be as specified in the referencing Code Section and the AE procedure (see T-1350).

APPENDIX III — NON-METALLIC COMPONENTS

III-1310 SCOPE

This Appendix specifies supplemental requirements for continuous monitoring of non-metallic (fiber reinforced plastic) components.

III-1320 BACKGROUND

Non-metallic (FRP) components such as pressure vessels, storage tanks, and piping, are typically used at relatively low temperature. Due to high attenuation and anisotropy of the material, AE methodology has proven to be more effective than other NDE methods.

III-1321 References

(a) Pressure Vessels. Section V, Article 11 — Acoustic Emission Examination of Fiberglass Tanks/Vessels

(b) Atmospheric Tanks. Section V, Article 11 — Acoustic Emission Examination of Fiberglass Vessels, ASNT/CARP Recommended Practice ASTM E 1067: Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin Tanks/Vessels

(c) Piping. ASTM E 1118 — Standard Practice for Acoustic Emission Examination of Reinforced Thermosetting Resin Pipe (RTRP)

III-1330 MATERIAL CONSIDERATIONS

High attenuation and anisotropy of the material are controlling factors in sensor frequency, source location accuracy, and sensor spacing.

III-1331 Sensor Frequency

Sensors used for monitoring FRP equipment shall be resonant in the 20–200 kHz frequency range.

III-1332 Source Location Accuracy

III-1332.1 Exact solution source location techniques shall be used in monitoring FRP where high accuracy is required. For these applications special precautions will be taken to account for unpredictable acoustic velocity variations in the material. Sensor spacing shall be no greater than 20 in. (508 mm).

III-1332.2 Zone location techniques require the AE signal to hit only one sensor to provide useful location

data. Sensor spacing of 5 ft–20 ft (1.5 m–6.0 m) may be used to cover large areas or the entire vessel.

III-1340 CALIBRATION

III-1341

A manufacturer's calibration of the instrumentation should be conducted on an annual basis. Instrumentation used for calibration shall be referenced to NIST.

III-1342

Periodic field calibration shall be performed with an AE waveform generator to verify performance of the signal processor.

III-1343

Hsu-Nielsen lead break and/or gas jet performance verification techniques (T-1362.2) shall be performed periodically to check all components including couplant, sensor, signal processor, and display.

III-1344

Low amplitude threshold (LAT) shall be determined using the 4 ft by 6 ft by ½ in. (1.2 m × 1.8 m × 13 mm) 99% pure lead sheet. The sheet shall be suspended clear of the floor. The LAT threshold is defined as the average measured amplitude of ten events generated by a 0.3 mm pencil (2H) lead break at a distance of 4 ft, 3 in. (1.3 m) from the sensor. All lead breaks shall be done at an angle of approximately 30 deg. to the surface with a 0.1 in. (2.5 mm) lead extension. The sensor shall be mounted 6 in. (152 mm) from the 4 ft (1.2 m) side and mid-distance between 6 ft (1.8 m) sides.

III-1345

High amplitude threshold (HAT) shall be determined using a 10 ft by 2 in. by 12 in. (3.0 m × 51 mm × 305 mm) clean, mild steel bar. The bar shall be supported at each end on elastomeric or similar isolating pads. The HAT threshold is defined as the average measured amplitude of ten events generated by a 0.3 mm pencil (2H) lead break at a distance of 7 ft (2.1 m) from the sensor. All lead breaks shall be done at an angle of approximately 30 deg. to the surface with a 0.1 in. (2.5 mm) extension. The sensor shall be mounted 12 in. (305 mm) from the end of the bar on the 2 in. (51 mm) wide surface.

III-1350 EVALUATION/RESULTS

III-1351 Evaluation Criteria

The monitoring procedure (T-1350) shall specify the acceptance criteria.

III-1351.1 AE activity above defined levels indicates that damage is occurring.

III-1351.2 Felicity ratio from subsequent loadings to a defined level can indicate the amount of previous damage.

III-1351.3 Emission activity during periods of contact load indicates that damage is occurring at an accelerating rate.

III-1352 Source Mechanism

III-1352.1 Matrix cracking, fiber debonding, and matrix crazing are characterized by numerous low amplitude acoustic emission signals. Matrix cracking and fiber debonding are generally the first indications of failure. Matrix crazing is normally an indication of corrosion or excessive thermal stress.

III-1352.2 Delamination is characterized by high signal strength, medium amplitude AE activity. This type of failure is typically found at joints with secondary bonds.

III-1352.4 High amplitude AE activity (over High Amplitude Threshold) is associated with fiber breakage and is an indication of significant structural damage.

APPENDIX IV — LIMITED ZONE MONITORING

IV-1310 SCOPE

This Appendix specifies supplemental requirements for applications involving limited zone monitoring, where one of the objectives is to consciously limit the area or volume of the component or pressure boundary that is monitored by AE. Typical reasons for limiting the monitored area include: (a) observe the behavior of a known flaw at a specific location; (b) restrict the AE response to signals emanating from specific areas or volumes of the pressure boundary (e.g., restrict the area monitored by AE to one or more nozzle-to-vessel welds, monitor specific structural welds, etc.); (c) restrict the AE examination to areas of known susceptibility to failure due to fatigue, corrosion, etc.; or (d) improve the signal-to-noise ratio.

TABLE II-1352
AN EXAMPLE OF EVALUATION CRITERIA FOR MULTISOURCE LOCATION

	Pressure Vessels (Other Than First Hydrostatic Test) Using Multisource Location
Emissions during hold	Not more than *E* hits from a cluster beyond time *T*
Count rate	Less than *N* counts from a cluster for a specified load increase
Number of hits	Not more than *E* hits from a cluster above a specified amplitude
Large amplitude	Not more than *E* hits from a cluster above a specified amplitude
Marse or aplitude	MARSE or amplitudes from a cluster do not increase with increasing load
Activity	Activity from a cluster does not increase with increasing load
Evaluation threshold, dB	50 dB or specified in procedure

IV-1320 TERMS SPECIFIC TO THIS APPENDIX

See Appendix VII for definitions of terms specific to this Appendix.

IV-1330 GENERAL

IV-1331 Techniques

Limited zone monitoring is accomplished by installing sensors in or around the area of interest. Signals originating from outside the area of interest are excluded from the analysis using techniques such as triangulation, amplitude discrimination, coincidence detection, or signal arrival sequence.

IV-1332 Guard Sensor Technique

One common signal arrival sequence technique uses guard sensors to limit the area of interest. The guard sensor technique involves placing additional sensors further outside the area of interest than the detection sensors. Signals arriving at a guard sensor before any of the detection sensors are rejected. Signals originating from within the area of interest arrive at a detection sensor before any of the guard sensors and are accepted by the data acquisition and analysis process.

IV-1333 Other Techniques

The preceding descriptions of typical limited zone monitoring techniques shall not preclude the use of other techniques to provide this function.

IV-1340 REQUIREMENTS

IV-1341 Procedure

When limited zone monitoring is intended, the technique used to accomplish this function shall be described in the procedure (T-1350). Any technique, or combination of techniques, may be utilized to accomplish limited zone monitoring provided the technique(s) is described in the applicable procedure.

IV-1342 Redundant Sensors

Where appropriate, redundant sensors should be used to provide additional assurance that the failure of a single sensor will not preclude continued operation of the AE system throughout the specified monitoring period.

IV-1343 System Calibration

During the system calibration performed in accordance with T-1362, the effectiveness of the limited zone monitoring technique(s) shall be demonstrated by introducing artificial AE signals both inside and outside the area of interest. The AE system shall accept at least 90% of the signals that originate inside the area of interest, and reject at least 90% of the signals that originate outside the area of interest. Such signal discrimination may be accomplished using any of the techniques listed above as specified in the procedure (T-1350).

IV-1350 EVALUATION/RESULTS

Data processing and interpretation shall be performed consistent with the objectives of limited zone monitoring. Precautions shall be taken to confirm that signals originating from inside the area of interest are not confused with signals originating from outside the area of interest. Care shall also be taken to check that the system's ability to monitor the area of interest was not compromised by excessive noise from outside the area of interest.

IV-1360 REPORTS/RECORDS

All reports of data acquired using the limited zone monitoring approach shall clearly and accurately identify the effective area of interest.

APPENDIX V — HOSTILE ENVIRONMENT APPLICATIONS

V-1310 SCOPE

This Appendix specifies supplemental requirements for continuous AE monitoring of pressure containing components during operation at high temperatures and in other hostile environments. As used herein, high temperature means as any application where the surface to be monitored will exceed 300°F (149°C), which is the nominal upper temperature limit for most general purpose AE sensors. Other hostile environments include corrosive environments, high vapor atmospheres, nuclear radiation, etc.

V-1320 SENSORS

For high temperature applications, special high temperature sensors shall be used. There are two basic types of sensors for such applications. Surface mounted sensors constructed to withstand high temperatures and waveguide sensors which remove the sensor's piezoelectric sensor from the high temperature environment through the use of a connecting waveguide. A thin, soft metal, interface layer between the sensor and the component surface has proven effective for reducing the interface pressure required to achieve adequate acoustic coupling.

V-1321 Surface Mounted Sensors

Sensors to be mounted directly on the surface shall be evaluated for their capability to withstand the environment for the duration of the planned monitoring period. Some sensors rated for high temperature service are limited in the time for which they can survive continuous exposure at their rated temperature.

V-1322 Waveguide Sensors

The waveguide sensors described below are suitable for hostile environment applications where the sensor unit (piezoelectric crystal and 20 dB preamplifier) can be placed in a less hostile environment [e.g., lower temperature of about 200°F (93°C)] through the use of a waveguide no more than 20 ft (6.1 m) long. The length of the waveguide is not an absolute; however, as the waveguide length increases, the signal attenuation in the waveguide also increases.

Waveguide sensors are a special type of sensor used for hostile environments. A type of waveguide sensor that has been used effectively to monitor components with surface temperatures to 1800°F (982°C) is shown in Fig. V-1322. A waveguide 20 ft (6.1 m) long was used to move the sensor unit (piezoelectric crystal and 20 dB preamplifier) away from the high temperature to an environment of about 200°F (93°C). The sensor was still exposed to a nuclear radiation environment of about 45,000 Rad/hr gross gamma. When monitoring was completed after 120 days, the sensors were still operating with no evidence of deterioration. These sensor types have been used in various applications with waveguide lengths ranging from 2 to 20 ft (0.6 m to 6.1 m) for periods up to 2½ years, and the attenuation in a 0.130 in. (3.30 mm) diameter Type 308 stainless steel waveguide has been measured to be 0.45 dB/ft.

V-1323 Sensor Monitoring

Refer to T-1332.3 for a discussion of sensor mounting. Most extreme temperature applications require mechanical mounting with pressure coupling of the sensors due to the temperature limitations of glues or epoxies. A sensor mounting fixture held in place by stainless steel bands or magnets has proven to be effective; however, if magnets are used, the ability of the magnet to retain its magnetic properties in the temperature environment must be evaluated. The fixture shown in Fig. V-1323 has been successfully used in a variety of waveguide sensor applications.

This fixture design provides a constant load on the waveguide tip against the component surface through the use of a spring. It has been found through practice that an interface pressure of about 16,000 psi (110 MPa) is required for good acoustic coupling. For the waveguide sensor shown in Fig. V-1322 with a waveguide tip diameter of 0.05 in. (1.27 mm), 30 pounds (0.13 kN) force for the mounting fixture provides the required interface pressure.

V-1324 Signal Cables

Special coaxial cables rated for the expected temperature shall be used to conduct AE signal information from the AE sensor to a location outside of the environment. Refer also to T-1333 and T-1348.

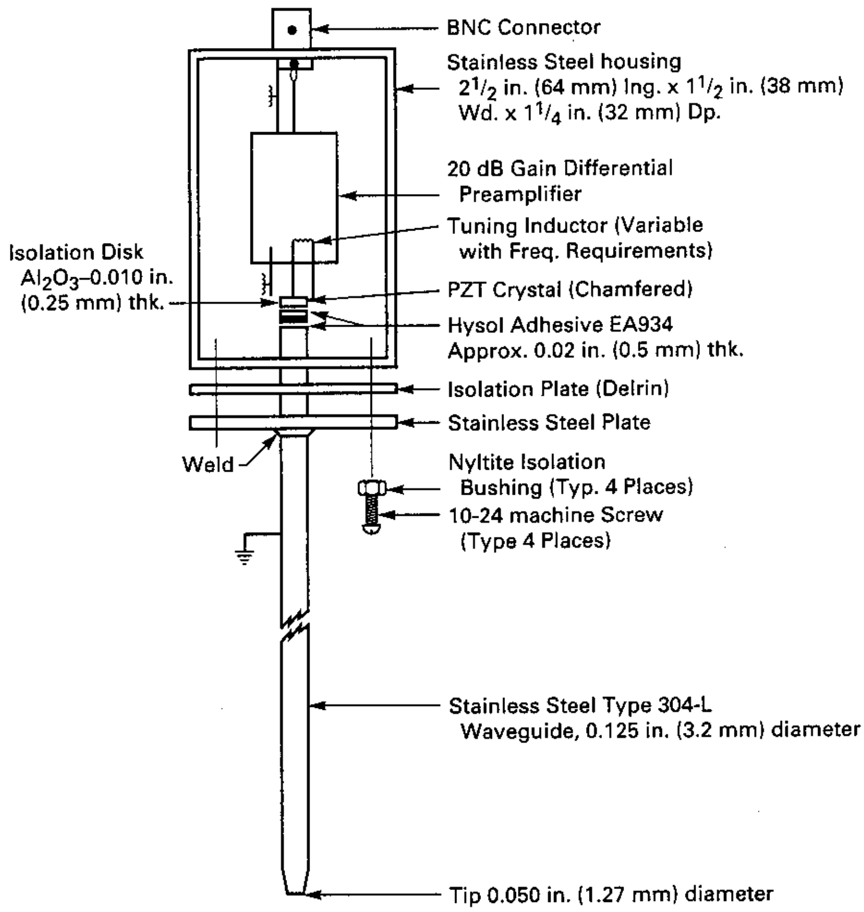


FIG. V-1322 METAL WAVEGUIDE AE SENSOR CONSTRUCTION

APPENDIX VI — LEAK DETECTION APPLICATIONS

VI-1310 SCOPE

This Appendix specifies supplemental requirements for continuous AE monitoring of metallic and nonmetallic components to detect leaks from the pressure boundary. The objective in examining the pressure boundary of systems and components is to assess the leak integrity and identify the leakage area. The requirements of Appendix I — Nuclear Components and Appendix V — Hostile Environment Applications may also be applicable. SE-1211 should be consulted as a general reference.

VI-1320 GENERAL

The desire to enhance leak detection capabilities has led to research to improve acoustic leak detection technology including technology that is applicable to the pressure boundary of nuclear reactors. Several methods are available for detecting leaks in pressure boundary components including monitoring acoustic noise due to fluid flow at a leakage site. The advantages of acoustic monitoring are rapid response to the presence of a leak and the capability to acquire quantitative information about a leak. Acoustic leak detection methods may be used to detect gas, steam, water, and chemical leaks for both nuclear and non-nuclear applications.

VI-1330 EQUIPMENT

VI-1331 Sensor Type

AE sensors with known sensitivity in the frequency range 200 kHz to 500 kHz shall be used in the presence of high background noise. For components in the

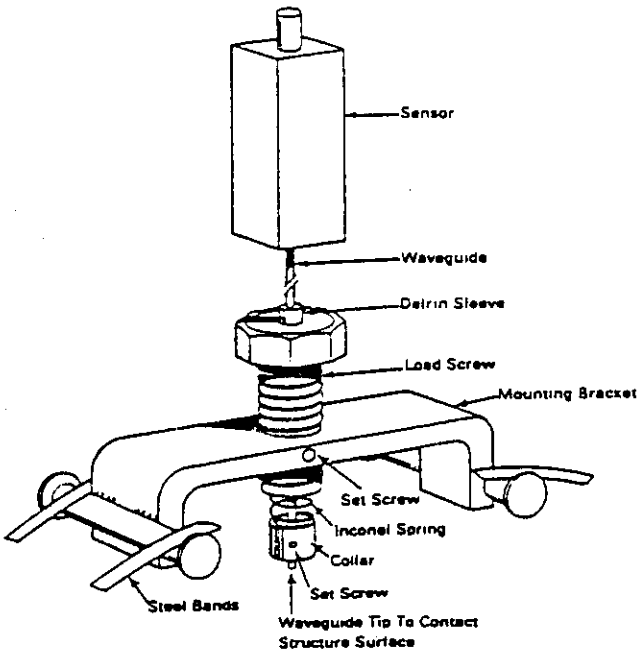


FIG. V-1323 MOUNTING FIXTURE FOR STEEL WAVEGUIDE AE SENSOR

presence of low background noise, monitoring shall be carried out at lower frequencies. Leak detection at frequencies below 100 kHz and as low as 1 kHz may be necessary for leak detection with non-metallic components.

VI-1331.1 Sensor selection shall be based on consideration of the following:

(*a*) center frequency
(*b*) bandwidth
(*c*) ruggedness
(*d*) response to temperature
(*e*) humidity
(*f*) ability of cables and preamplifiers to withstand the specific environment.

Using a simulation, sensor response characteristics and curves of leak rate vs. acoustic signal intensity shall be determined before installation to maximize the utility of the information in the acoustic signal.

VI-1331.2 Sensors not specified in this Appendix may be used if they have been shown to be appropriate for the application and meet the requirements of this Article. Alternate sensors, such as accelerometers, microphones, and hydrophones shall be included.

VI-1332 Waveguide

Waveguides may be used to isolate the sensor from hostile environments such as high temperatures or nuclear radiation for nuclear reactor applications.

VI-1332.1 Waveguide installations shall consider the following waveguide parameters:

(*a*) length
(*b*) diameter
(*c*) surface finish
(*d*) material of construction (i.e., ferritic steel, stainless steel, aluminum, and ceramic materials)

Waveguides having 3 mm to 13 mm in diameter and up to 250 mm in length have been shown to be effective and shall be used.

VI-1332.2 Coupling. Appendix V, para. V-1323 describes one method for mounting the waveguide. Others that have been shown effective are:

(*a*) weld the waveguide to the pressure boundary
(*b*) screw the waveguide into a plate attached to the order to mechanically press the waveguide against the metal component
(*c*) screw the waveguide directly into the pressure boundary component
(*d*) attach the sensor directly to the component.

Either gold foil or rounded waveguide tips have been shown to be effective when mechanically coupling the waveguide to the pressure boundary component. Occassionally, sensors are mounted and passed through the pressure boundary of a component in order to have the sensor in the process fluid. The sensor(s) shall then be capable of withstanding the ambient service environment of the process fluid. In addition, a safety analysis for installation and monitoring of the system shall be performed.

VI-1333 Electronic Filters

The response of the electronic filter(s) shall be adjustable to achieve the selected monitoring frequency range of operation as needed (see Appendix I). Frequency bandwidths in the range of 200–250 kHz should be available for high background noise environments and 1–200 kHz for low background noise environments.

VI-1340 CALIBRATION

VI-1341 Procedure

A calibration procedure shall be established and shall incorporate either the pencil-lead break and/or gas jet techniques decribed in T-1360 and Appendix I.

VI-1342 Calibration Checks

Sensor calibration checks may be conducted by electronically pulsing one of the sensors while detecting the associated acoustic wave with the other sensors.

VI-1350 EXAMINATION

VI-1351 Implementation of System Requirements

In order to implement an acoustic leak detection and location system, the following preliminary steps shall be accomplished.

(a) identify the acoustic receiver sites

(b) determine the spacing between waveguides or sensors

(c) meet the sensitivity needs for the system requirements

(d) establish the level of background noise

(e) estimate signal-to-noise ratios as a function of distance and level of background noise for acoustic signals in the frequency range selected.

VI-1352 Calibration Procedure

A calibration procedure shall be established. During the monitoring period, a self-checking system shall be performed to assure the system is functioning properly.

VI-1353 Equipment Qualification and Calibration Data

The acoustic equipment qualification and calibration data requirements shall be in accordance with T-1392.

VI-1360 EVALUATION/RESULTS

VI-1361 Leak Indications

Detection of a leak or leakage indication near or at a sensor site will be indicated by an increase in the RMS signal over background noise. The signal increase shall be at least 3 dB or greater above background for a period of at least 30 min.

VI-1362 Leak Location

The general location of a leak can be established by the analysis of the relative amplitude of the RMS signals received by the sensor(s). Leak location may also be determined by cross-correlation analysis of signals received at sensors, to either side of the leak site. When leakage location accuracy is desired, it may be necessary to spatially average the correlograms of the acoustic signals at each sensor site by installing an array of sensors. A minimum of three waveguides, separated by a minimum of 10 cm, is required for averaging of correlograms. This allows nine correlograms to be generated and averaged for each pair of sensor locations. Self-checking and calibration for the system shall be in accordance with VI-1340. If acoustic background levels are relatively constant, they may also be used to determine whether a probe is failing.

APPENDIX VII — GLOSSARY OF TERMS FOR ACOUSTIC EMISSION EXAMINATION

VII-1310 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms that appear in Article 13, Continuous Acoustic Emission Monitoring.

VII-1320 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 provides the definitions of terms listed in VII-1330(a).

(c) For general terms, such as *Interpretation, Flaw, Discontinuity, Evaluation,* etc., refer to Article 1, Mandatory Appendix I.

(d) Paragraph VII-1330(b) provides a list of terms and definitions that are in addition to SE-1316 and are Code specific.

VII-1330 REQUIREMENTS

(a) All of the terms listed in SE-1316 are used in conjunction with this Article.

(b) The following Code terms are used in conjunction with this Article:

AE Monitor — all of the electronic instrumentation and equipment (except sensors and cables) used to detect, analyze, display, and record AE signals

Continuous Monitoring — the process of monitoring a pressure boundary continuously to detect acoustic emission during plant startup, operation, and shutdown

dB_{AE} — the peak voltage amplitude of the acoustic emission signal waveform expressed by the equation $dB_{AE} = 20 \log V/V_{Ref}$, where V_{Ref} is 1 μV out of the AE sensor crystal

Limited Zone Monitoring — the process of monitoring only a specifically defined portion of the pressure boundary by using either the sensor array configuration, controllable instrumentation parameters, or both to limit the area being monitored

Penetrations — In nuclear applications, the term penetrations refers to step-plugs containing electronic instrumentation cable sections installed through shielding or containment walls to permit passing instrumentation power and information signals through these protective walls without compromising the protective integrity of the wall

Plant/Plant System — the complete pressure boundary system including appurtenances, accessories, and controls that constitute an operational entity

Plant Operation — normal operation including plant warmup, startup, shutdown, and any pressure or other stimuli induced to test the pressure boundary for purposes other than the stimulation of AE sources

Sensor Array — mulitple AE sensors arranged in a geometrical configuration that is designed to provide AE source detection/location for a given plant component or pressure boundary area to be monitored

Subsection B

Documents Adopted by Section V

SUBSECTION B

01

ARTICLE 22
RADIOGRAPHIC STANDARDS

STANDARD GUIDE FOR RADIOGRAPHIC TESTING

SE-94

(Identical with ASTM Specification E 94-93)

1. Scope

1.1 This guide covers satisfactory X-ray and gamma-ray radiographic testing as applied to industrial radiographic film recording. It includes statements about preferred practice without discussing the technical background which justifies the preference. A bibliography of several textbooks and standard documents of other societies is included for additional information on the subject.

1.2 This guide covers types of materials to be inspected; radiographic testing techniques and production methods; radiographic film section, processing, viewing, and storage; maintenance of inspection records; and a list of available reference radiograph documents.

NOTE 1 — Further information is contained in Guide E 999, Practice E 1025, Test Method E 1030, and Method E 1032.

1.3 *Interpretation and Acceptance Standards* — Interpretation and acceptance standards are not covered by this guide, beyond listing the available reference radiograph documents for casting and welds. Designation of accept-reject standards is recognized to be within the cognizance of product specifications and generally a matter of contractual agreement between producer and purchaser.

1.4 *Safety Practices* — Problems of personnel protection against X-rays and gamma rays are not covered by this document. For information on this important aspect of radiography, reference should be made to the current document of the National Committee on Radiation Protection and Measurement, Federal Register, U.S. Energy Research and Development Administration, National Bureau of Standards, and to state and local regulations, if such exist.

1.5 *This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.6 If an NDT agency is used, the agency shall be qualified in accordance with Practice E 543.

2. Referenced Documents

2.1 *ASTM Standards:*

E 142 Method for Controlling Quality of Radiographic Testing

E 543 Practice for Evaluating Agencies that Perform Nondestructive Testing

E 746 Test Method for Determining the Relative Image Quality Response of Industrial Radiographic Film

E 747 Test Method for Controlling Quality of Radiographic Testing Using Wire Penetrameters

E 801 Practice for Controlling Quality of Radiographic Testing of Electronic Devices

E 999 Guide for Controlling the Quality of Industrial Radiographic Film Processing

E 1025 Practice for Hole-Type Image Quality Indicators Used for Radiography

E 1030 Test Method for Radiographic Testing of Metallic Castings

E 1032 Method for Radiographic Examination of Weldments

E 1079 Practice for Calibration of Transmission Densitometers

E 1254 Guide for Storage of Radiographs and Unexposed Industrial Radiographic Films

E 1316 Terminology for Nondestructive Examinations

2.2 *ANSI Standards:*

PH1.41 Specifications for Photographic Film for Archival Records, Silver-Gelatin Type, on Polyester Base

PH2.22 Methods for Determining Safety Times of Photographic Darkroom Illumination

PH4.8 Methylene Blue Method for Measuring Thiosulfate and Silver Densitometric Method for Measuring Residual Chemicals in Films, Plates, and Papers
T9.1 Imaging Media (Film) — Silver-Gelatin Type Specifications for Stability
T9.2 Imaging Media — Photographic Processed Films, Plates, and Papers — Filing Enclosures and Storage Containers

3. Terminology

3.1 *Definitions* — For definitions of terms used in this guide, refer to Terminology E 1316.

4. Significance and Use

4.1 Within the present state of the radiographic art, this guide is generally applicable to available materials, processes, and techniques where industrial X-ray films are used as the recording media.

4.2 *Limitations* — This guide does not take into consideration special benefits and limitations resulting from the use of nonfilm recording media or readouts such as paper, tapes, xeroradiography, fluoroscopy, and electronic image intensification devices. Although reference is made to documents that may be used in the identification and grading, where applicable, of representative discontinuities in common metal castings and welds, no attempt has been made to set standards of acceptance for any material or production process. Radiography will be consistent in sensitivity and resolution only if the effect of all details of techniques, such as geometry, film, filtration, viewing, etc., is obtained and maintained.

PART I — EQUIPMENT AND PROCEDURE

5. Radiographic Quality Level

5.1 The quality level usually required for radiography is 2% (2-2T when using hole type IQI) unless a higher or lower quality is agreed upon between the purchaser and the supplier. At the 2% subject contrast level, three quality levels of inspection, levels 2-1T, 2-2T, and 2-4T, are available through the design and application of the IQI Practice E 1025, Table 1. The level of inspection specified should be based on the service requirements of the product. Great care should be taken in specifying quality levels 2-1T, 1-1T, and 1-2T by first determining that these quality levels can be maintained in production radiography.

NOTE 2 — The first number of the quality level designation refers to IQI thickness expressed as a percentage of specimen thickness; the second number refers to the diameter of the IQI hole that must be visible on the radiograph, expressed as a multiple of penetrameter thickness, *T*.

5.2 If IQIs of material radiographically similar to that being examined are not available, IQIs of the required dimensions but of a lower-absorption material may be used.

5.3 The quality level required using wire IQIs shall be equivalent to the 2-2T level of Practice E 1025 unless a higher or lower quality level is agreed upon between purchaser and supplier. Table 4 of Test Method E 747 gives a list of various hole-type IQIs and the diameter of the wires of corresponding EPS with the applicable 1T, 2T, and 4T holes in the plaque IQI. Appendix XI of Test Method E 747 gives the equation for calculating other equivalencies, if needed.

6. Energy Selection

6.1 X-ray energy affects image quality. In general, the lower the energy of the source utilized the higher the achievable radiographic contrast, however, other variables such as geometry and scatter conditions may override the potential advantage of higher contrast. For a particular energy, a range of thicknesses, which are a multiple of the half value layer, may be radiographed to an acceptable quality level utilizing a particular X-ray machine or gamma ray source. In all cases the specified IQI (penetrameter) quality level must be shown on the radiograph. In general, satisfactory results can normally be obtained for X-ray energies between 100 kV to 500 kV in a range between 2.5 to 10 half value layers (HVL) of material thickness (see Table 1). This range may be extended by as much as a factor of 2 in some situations for X-ray energies in the 1–25 MV range primarily because of reduced scatter.

7. Radiographic Equivalence Factors

7.1 The radiographic equivalence factor of a material is that factor by which the thickness of the material must be multiplied to give the thickness of a "standard" material (often steel) which has the same absorption. Radiographic equivalence factors of several of the more common metals are given in Table 2, with steel arbitrarily assigned a factor of 1.0. The factors may be used:

7.1.1 To determine the practical thickness limits for radiation sources for materials other than steel, and

TABLE 1
TYPICAL STEEL HVL THICKNESS IN INCHES (MM) FOR COMMON ENERGIES

Energy	Thickness, in. (mm)
120 kV	0.10 (2.5)
150 kV	0.14 (3.6)
200 kV	0.20 (5.1)
250 kV	0.25 (6.4)
400 kV (Ir 192)	0.35 (8.9)
1 Mv	0.57 (14.5)
2 Mv (Co 60)	0.80 (20.3)
4 Mv	1.00 (25.4)
6 Mv	1.15 (29.2)
10 Mv	1.25 (31.8)
16 Mv and higher	1.30 (33.0)

TABLE 2
APPROXIMATE RADIOGRAPHIC EQUIVALENCE FACTORS FOR SEVERAL METALS (RELATIVE TO STEEL)

	Energy Level									
Metal	100 kV	150 kV	220 kV	250 kV	400 kV	1 MV	2 MV	4 to 25 MV	^{192}Ir	^{60}Co
Magnesium	0.05	0.05	0.08							
Aluminum	0.08	0.12	0.18						0.35	0.35
Aluminum alloys	0.10	0.14	0.18						0.35	0.35
Titanium		0.54	0.54		0.71	0.9	0.9	0.9	0.9	0.9
Iron/all steels	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Copper	1.5	1.6	1.4	1.4	1.4	1.1	1.1	1.2	1.1	1.1
Zinc		1.4	1.3		1.3			1.2	1.1	1.0
Brass		1.4	1.3		1.3	1.2	1.1	1.0	1.1	1.0
Inconel X		1.4	1.3		1.3	1.3	1.3	1.3	1.3	1.3
Monel	1.7		1.2							
Zirconium	2.4	2.3	2.0	1.7	1.5	1.0	1.0	1.0	1.2	1.0
Lead	14.0	14.0	12.0			5.0	2.5	2.7	4.0	2.3
Hafnium			14.0	12.0	9.0	3.0				
Uranium			20.0	16.0	12.0	4.0		3.9	12.6	3.4

7.1.2 To determine exposure factors for one metal from exposure techniques for other metals.

8. Film

8.1 Various industrial X-ray film types are available to meet the needs of production radiographic work. However, definite rules on the selection of film are difficult to formulate because the choice depends on individual user requirements. Some user requirements are as follows: radiographic quality levels, exposure times, and various cost factors. Several methods are available for assessing image quality levels (see Method E 142, Test Methods E 746 and E 747, and Practice E 801). Information about specific products can be obtained from the manufacturers.

9. Filters

9.1 *Definition* — Filters are uniform layers of material placed between the radiation source and the film.

9.2 *Purpose* — The purpose of filters is to absorb the softer components of the primary radiation, thus resulting in one or several of the following practical advantages:

9.2.1 Decreasing scattered radiation, thus increasing contrast.

9.2.2 Decreasing undercutting, thus increasing contrast.

9.2.3 Decreasing contrast of parts of varying thickness.

9.3 *Location* — Usually the filter will be placed in one of the following two locations:

9.3.1 As close as possible to the radiation source, which minimizes the size of the filter and also the contribution of the filter itself to scattered radiation to the film.

9.3.2 Between the specimen and the film in order to absorb preferentially the scattered radiation from the specimen. It should be noted that lead foil and other metallic screens (see 12.1) fulfill this function.

9.4 *Thickness and Filter Material* — The thickness and material of the filter will vary depending upon the following:

9.4.1 The material radiographed.

9.4.2 Thickness of the material radiographed.

9.4.3 Variation of thickness of the material radiographed.

9.4.4 Energy spectrum of the radiation used.

9.4.5 The improvement desired (increasing or decreasing contrast). Filter thickness and material can be calculated or determined empirically.

10. Masking

10.1 Masking or blocking (surrounding specimens or covering thin sections with an absorptive material) is helpful in reducing scattered radiation. Such a material can also be used to equalize the absorption of different sections, but the loss of detail may be high in the thinner sections.

11. Back-Scatter Protection

11.1 Effects of back-scattered radiation can be reduced by confining the radiation beam to the smallest practical cross section and by placing lead behind the film. In some cases either or both the back lead screen and the lead contained in the back of the cassette or film holder will furnish adequate protection against back-scattered radiation. In other instances, this must be supplemented by additional lead shielding behind the cassette or film holder.

11.2 If there is any question about the adequacy of protection from back-scattered radiation, a characteristic symbol [frequently a $^1/_8$-in. (3.2-mm) thick letter *B*] should be attached to the back of the cassette or film holder, and a radiograph made in the normal manner. If the image of this symbol appears on the radiograph as a lighter density than background, it is an indication that protection against back-scattered radiation is insufficient and that additional precautions must be taken.

12. Screens

12.1 *Metallic Foil Screens:*

12.1.1 Lead foil screens are commonly used in direct contact with the films, and, depending upon their thickness, and composition of the specimen material, will exhibit and intensifying action at as low as 90 kV. In addition, any screen used in front of the film acts as a filter (Section 9) to preferentially absorb scattered radiation arising from the specimen, thus improving radiographic quality. The selection of lead screen thickness, or for that matter, any metallic screen

thickness, is subject to the same considerations as outlined in 9.4. Lead screens lessen the scatter reaching the film regardless of whether the screens permit a decrease or necessitate an increase in the radiographic exposure. To avoid image unsharpness due to screens, there should be intimate contact between the lead screen and the film during exposure.

12.1.2 Lead foil screens of appropriate thickness should be used whenever they improve radiographic quality or penetrameter sensitivity or both. The thickness of the front lead screens should be selected with care to avoid excessive filtration in the radiography of thin or light alloy materials, particularly at the lower kilovoltages. In general, there is no exposure advantage to the use of 0.005 in. in front and back lead screens below 125 kV in the radiography of $^1/_4$-in. (6.35-mm) or lesser thickness steel. As the kilovoltage is increased to penetrate thicker sections of steel, however, there is a significant exposure advantage. In addition to intensifying action, the back lead screens are used as protection against back-scattered radiation (see Section 11) and their thickness is only important for this function. As exposure energy is increased to penetrate greater thicknesses of a given subject material, it is customary to increase lead screen thickness. For radiography using radioactive sources, the minimum thickness of the front lead screen should be 0.005 in. (0.13 mm) for iridium-192, and 0.010 in. (0.25 mm) for cobalt-60.

12.2 *Other Metallic Screen Materials:*

12.2.1 Lead oxide screens perform in a similar manner to lead foil screens except that their equivalence in lead foil thickness approximates 0.0005 in. (0.013 mm).

12.2.2 Copper screens have somewhat less absorption and intensification than lead screens, but may provide somewhat better radiographic sensitivity with higher energy above 1 MV.

12.2.3 Gold, tantalum, or other heavy metal screens may be used in cases where lead cannot be used.

12.3 *Fluorescent Screens* — In general, for a given source of radiation, fluorescent screens should be used only when the exposure necessary without them would be prohibitively long. In any event, if fluorescent screens must be used, they should be proven capable of achieving the required quality level. Good screen–film contact is essential for the successful use of fluorescent screens.

12.4 *Screen Care* — All screens should be handled carefully to avoid dents and scratches, dirt, or grease on active surfaces. Grease and lint may be removed from lead screens with a solvent. Fluorescent screens should be cleaned in accordance with the recommendations of the manufacturer. Screens showing evidence of physical damage should be discarded.

13. Radiographic Contrast

13.1 The various radiation intensities that penetrate an object are rendered as different photographic densities in a radiograph. Using transmitted or reflected light to view a radiograph, an observed change in film density over a background is defined as contrast. Radiographic contrast depends mostly upon subject contrast and film gradient.

13.2 Subject contrast is the ratio of radiation intensities transmitted by two selected portions of a specimen.

13.3 The film gradient is the value of the slope of the tangent line drawn to a particular density point on the characteristic curve to the abscissa. Film manufacturers can furnish characteristic curves of their products.

13.4 The quality of radiography is influenced by many variables; the effects of changes in some of these variables are illustrated in Fig. 1.

14. Geometry

14.1 The focus-film distance necessary to reduce geometric unsharpness to a negligible amount depends upon the film or film-screen combinations, focal-spot size, and object–film distance. Geometric unsharpness is given [see Fig. 2(a)] by the equation:

$$U_g = Ft/d_o$$

where:

U_g = geometric unsharpness,
F = size of the radiation source,
t = specimen thickness, when in contact with the film, and
d_o = source–object distance.

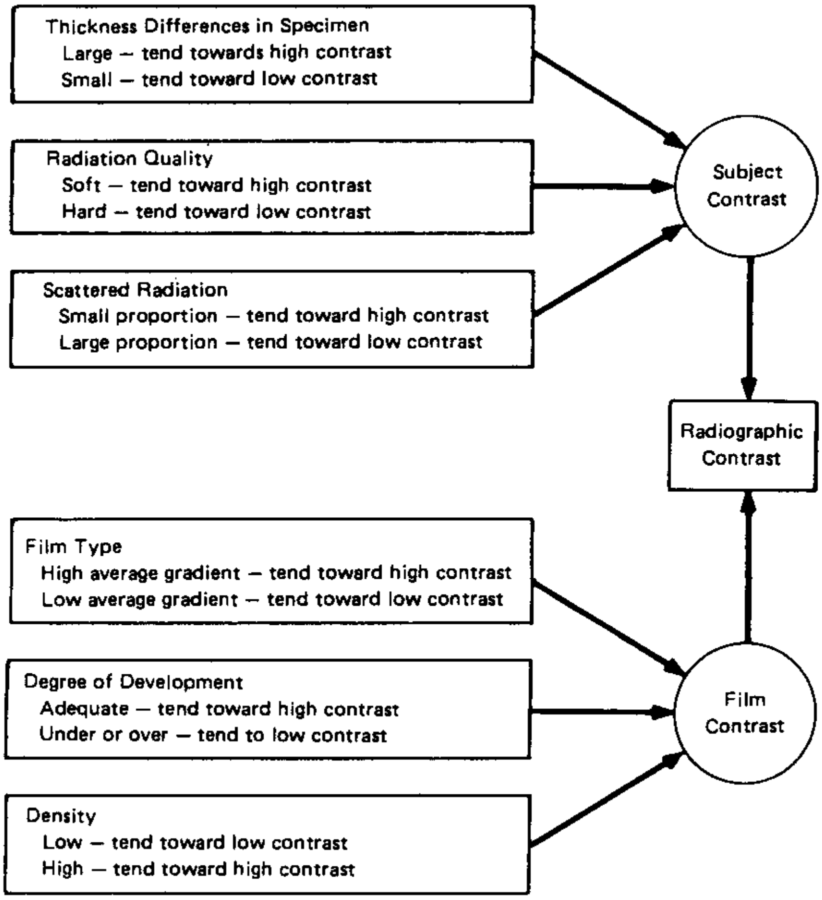
NOTE 3 — d_o and t must be in the same units of measure; the units of U_g will be in the same units as F.

NOTE 4 — A nomogram for the determination of U_g is given in Fig. 3 (inch-pound units). Fig. 4 represents a nomogram in metric units.

Example:

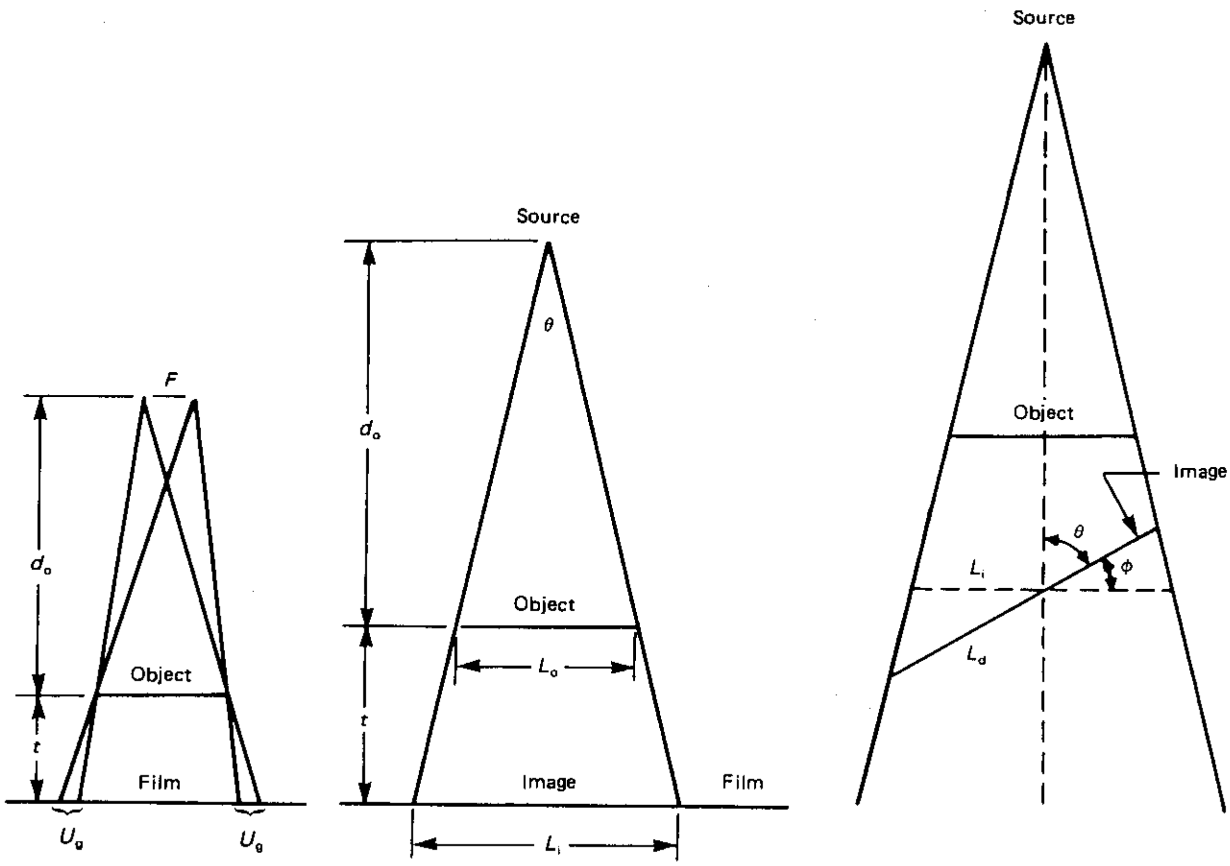
Given:

Source–film distance (d_o) = 40 in.,
Source size (F) = 500 mils, and
Source side of specimen to film distance (t) = 1.5 in.



GENERAL NOTE: The maximum usable density on Class 1, 2, and 3 film depends on the illuminator available.

FIG. 1 EFFECTS OF CHANGES IN VARIABLES ON QUALITY OF RADIOGRAPHY



(a) Geometric Unsharpness **(b) Radiographic Enlargement** **(c) Radiographic Distortion**

LEGEND:
d_o = source-to-object distance
t = object-to-film distance
L_o = dimension of object
L_i = dimension of image
$U_g = Ft/d_o$

LEGEND:
L_i = dimension of undistorted image
L_d = dimension of distorted image
$L_d - L_i = \Delta L$
Percentage distortion = $(\Delta L/L_i) \times 100$

$L_i - L_o = \Delta L = 2t \times \tan 1/2\theta$
$\Delta L/L_o \times 100$ = percentage enlargement

FIG. 2 EFFECTS OF OBJECT–FILM GEOMETRY

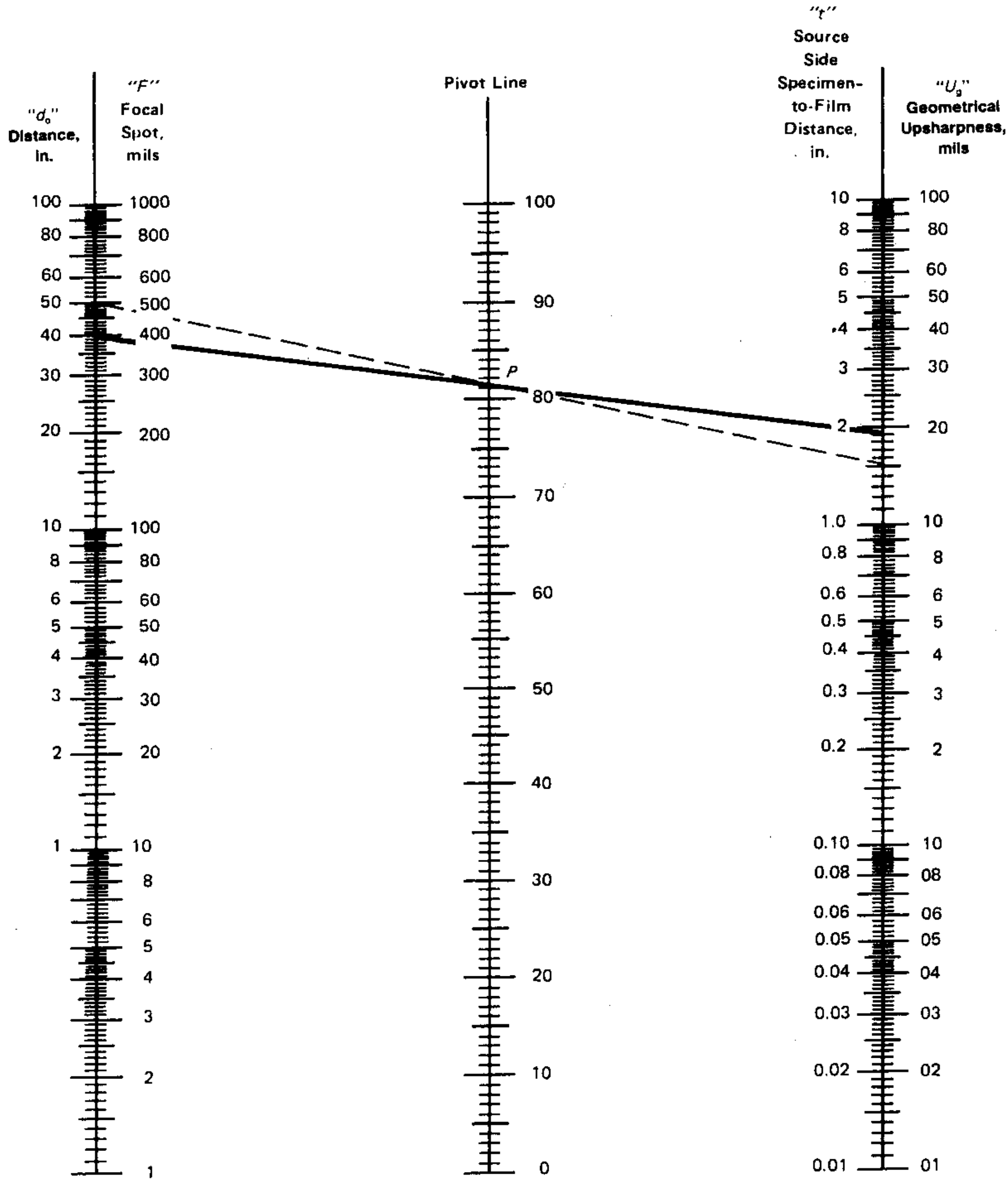


FIG. 3 NOMOGRAM FOR DETERMINING GEOMETRIC UNSHARPNESS
(Inch-Pound Units)

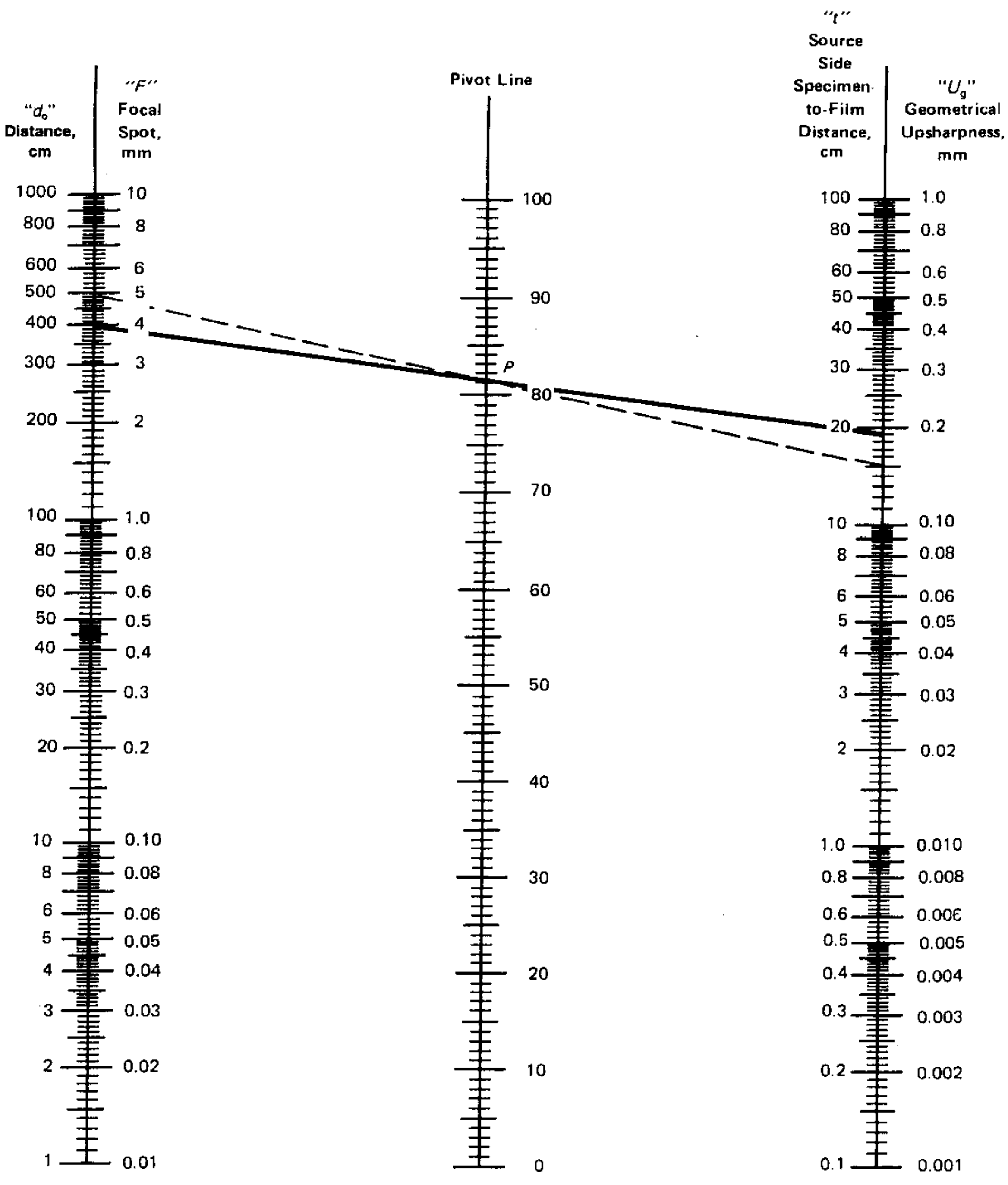


FIG. 4 NOMOGRAM FOR DETERMINING GEOMETRIC UNSHARPNESS
(Metric Units)

Draw a straight line (dashed in Fig. 3) between 500 mils on the F scale and 1.5 in. on the t scale. Note the point on intersection (P) of this line with the pivot line. Draw a straight line (solid in Fig. 3) from 40 in. on the d_0 scale through point P and extend to the U_g scale. Intersection of this line with the U_g scale gives geometrical unsharpness in millimetres, which in the example is 19 mils.

Inasmuch as the source size, F, is usually fixed for a given radiation source, the value of U_g is essentially controlled by the simple d_0/t ratio.

14.2 Because X and gamma radiation is divergent, the radiographic image of an object, or of a structure within an object, will be larger than the object or the structure itself. The degree of enlargement will increase with decreasing source–object (structure) distance and with increasing object (structure)–film distance [Fig. 2(b)].

14.3 If the film is not parallel to the object, the radiographic image will be distorted because different parts of the radiographic image will be enlarged by different amounts. A measure of the degree of distortion is given by the ratio of the change in image size caused by distortion to the size of the undistorted image [Fig. 2(c)].

14.4 Final acceptance of radiographs should be based on the ability to see the prescribed penetrameter image and the specified hole. The unsharpness formula is included for information and guidance, and will operate within practical limits, but is of less consequence as d_o/t ratios increase.

15. Exposure Calculations or Charts

15.1 Development or procurement of an exposure chart or calculator is the responsibility of the individual laboratory.

15.2 The essential elements of an exposure chart or calculator must relate the following:

15.2.1 Source or machine,

15.2.2 Material type,

15.2.3 Material thickness,

15.2.4 Film type (relative speed),

15.2.5 Film density (see Note 5),

15.2.6 Source or focus-film distance,

15.2.7 Kilovoltage or isotope type,

NOTE 5 — For detailed information of film density and density measurement calibration, see Practice E 1079.

15.2.8 Screen type and thickness,

15.2.9 Curies or milliamperes,

15.2.10 Time of exposure,

15.2.11 Filter (in the primary beam),

15.2.12 Time–temperature development for hand processing; access time for automatic processing; time–temperature development for dry processing, and

15.2.13 Processing chemistry brand name, if applicable.

15.3 The essential elements listed in 15.2 will be accurate for isotopes of the same type, but will vary with X-ray equipment of the same kilovoltage and milliampere rating.

15.4 Exposure charts should be developed for each X-ray machine and corrected each time a major component is replaced, such as the X-ray tube or high-voltage transformer.

15.5 The exposure chart should be corrected when the processing chemicals are changed to a different manufacturer's brand or the time–temperature relationship of the processor may be adjusted to suit the exposure chart. The exposure chart, when using a dry processing method, should be corrected based upon the time–temperature changes of the processor.

16. Technique File

16.1 It is recommended that a radiographic technique log or record containing the essential elements be maintained.

16.2 The radiographic technique log or record should contain the following:

16.2.1 Description or sketch of the object,

16.2.2 Material type and thickness,

16.2.3 Source or focus–film distance,

16.2.4 Film type,

16.2.5 Film density,

16.2.6 Screen type and thickness,

16.2.7 Isotope or X-ray machine identification,

16.2.8 Curie or milliampere minutes,

16.2.9 Film placement for nonstandard items,

16.2.10 Source position for nonstandard items,

16.2.11 Penetrameter and shim thickness,

16.2.12 Special masking or filters,

16.2.13 Collimator or field limitation device, and

16.2.14 Processing method.

16.3 The recommendations of 16.2 are not mandatory, but are essential in reducing the overall cost of radiography, and serve as a communication link between the radiographic interpreter and the radiographic operator.

17. Penetrameters (Image Quality Indicators)

17.1 The selection and placement of penetrameters shall be in accordance with applicable standards Method E 142, Test Method E 747, and Practices E 801 and E 1025.

17.2 Another image quality indicator (IQI) may be found in Test Method E 746 for determining relative image quality response of industrial X-ray films at 200 KEV.

17.2.1 However, the E 746 Equivalent Penetrameter Sensitivity (EPS) plaque may be used to study the effects of various radiographic variables on radiographic system EPS performance.

17.2.2 For example, multiple X-ray machines may be observed for their effect on EPS by holding film and processing constant and taking image quality exposures with all the X-ray machines. The machines would be set for the given exposure condition in Test Method E 746 and film density equalized. By reading the resultant films, the relative EPS variations between machines may be determined.

17.2.3 Exposure condition variables may also be studied using this plaque.

17.2.4 While Test Method E 746 plaque can be useful in quantifying relative radiographic image quality, these other applications of the plaque may be useful.

18. Identification of and Location Markers on Radiographs

18.1 *Identification of Radiographs:*

18.1.1 Each radiograph must be identified uniquely so that there is a permanent correlation between the part radiographed and the film. The type of identification and method by which identification is achieved shall be as agreed upon between the customer and inspector.

18.1.2 The minimum identification should at least include the following: the radiographic facility's name, the date, part number and serial number, if used, for unmistakable identification of radiographs with the specimen. The letter *R* should be used to designate a radiograph of a repair area, and may include -1 , -2, etc., for the number of repair.

18.2 *Location Markers:*

18.2.1 Location markers (that is, lead or high-atomic number metals or letters that are to appear as images on the radiographic film) should be placed on the part being examined, whenever practical, and not on the cassette. Their exact locations should also be marked on the surface of the part being radiographed, thus permitting the area of interest to be located accurately on the part, and they should remain on the part during radiographic inspection. Their exact location may be permanently marked in accordance with the customer's requirements.

18.2.2 Location markers are also used in assisting the radiographic interpreter in marking off defective areas of components, castings, or defects in weldments; also, sorting good and rejectable items when more than one item is radiographed on the same film.

18.2.3 Sufficient markers must be used to provide evidence on the radiograph that the required coverage of the object being examined has been obtained, and that overlap is evident, especially during radiography of weldments and casting.

18.2.4 Parts that must be identified permanently may have the serial numbers or section numbers, or both, stamped or written upon them with a marking pen with a special indelible ink, engraved, die stamped, or etched. In any case, the part should be marked in an area not to be removed in subsequent fabrication. If die stamps are used, caution is required to prevent breakage or future fatigue failure. The lowest stressed surface of the part should be used for this stamping. Where marking or stamping of the part is not permitted for some reason, a marked reference drawing or shooting sketch is recommended.

PART II — PROTECTION AND CARE OF UNPROCESSED FILM

19. Storage of Film

19.1 Unexposed films should be stored in such a manner that they are protected from the effects of light, pressure, excessive heat, excessive humidity, damaging

fumes or vapors, or penetrating radiation. Film manufacturers should be consulted for detailed recommendations on film storage. Storage of film should be on a "first in," "first out" basis.

19.2 More detailed information on film storage is provided in Guide E 1254.

20. Safelight Test

20.1 Films should be handled under safelight conditions in accordance with the film manufacturer's recommendations. ANSI PH2.22 can be used to determine the adequacy of safelight conditions in a darkroom.

21. Cleanliness and Film Handling

21.1 Cleanliness is one of the most important requirements for good radiography. Cassettes and screens must be kept clean, not only because dirt retained may cause exposure or processing artifacts in the radiographs, but because such dirt may also be transferred to the loading bench, and subsequently to other film or screens.

21.2 The surface of the loading bench must be kept clean. Where manual processing is used, cleanliness will be promoted by arranging the darkroom with processing facilities on one side and film-handling facilities on the other. The darkroom will then have a wet side and a dry side and the chance of chemical contamination of the loading bench will be relatively slight.

21.3 Films should be handled only at their edges, and with dry, clean hands to avoid finger marks on film surfaces.

21.4 Sharp bending, excessive pressure, and rough handling of any kind must be avoided.

PART III — PROCESSING FILMS AND VIEWING AND STORING RADIOGRAPHS

22. Film Processing, General

22.1 To produce a satisfactory radiograph, the care used in making the exposure *must* be followed by equal care in processing. The most careful radiographic techniques can be nullified by incorrect or improper darkroom procedures.

22.2 More detailed information on film processing is provided in Guide E 999.

23. Automatic Processing

23.1 *Automatic Processing* — The essence of the automatic processing system is control. The processor maintains the chemical solutions at the proper temperature, agitates and replenishes the solutions automatically, and transports the films mechanically at a carefully controlled speed throughout the processing cycle. Film characteristics must be compatible with processing conditions. It is, therefore, essential that the recommendations of the film, processor, and chemical manufacturers be followed.

23.2 *Automatic Processing, Dry* — The essence of dry automatic processing is the precise control of development time and temperature which results in reproducibility of radiographic density. Film characteristics must be compatible with processing conditions. It is, therefore, essential that the recommendations of the film and processor manufacturers be followed.

24. Manual Processing

24.1 Film and chemical manufacturers should be consulted for detailed recommendations on manual film processing. This section outlines the steps for one acceptable method of manual processing.

24.2 *Preparation* — No more film should be processed than can be accommodated with a minimum separation of $^1/_2$ in. (12.7 mm). Hangers are loaded and solutions stirred before starting development.

24.3 *Start of Development* — Start the timer and place the films into the developer tank. Separate to a minimum distance of $^1/_2$ in. (12.7 mm) and agitate in two directions for about 15 s.

24.4 *Development* — Normal development is 5 to 8 min at 68°F (20°C). Longer development time generally yields faster film speed and slightly more contrast. The manufacturer's recommendation should be followed in choosing a development time. When the temperature is higher or lower, development time must be changed. Again, consult manufacturer-recommended development time versus temperature charts. Other recommendations of the manufacturer to be followed are replenishment rates, renewal of solutions, and other specific instructions.

24.5 *Agitation* — Shake the film horizontally and vertically, ideally for a few seconds each minute during development. This will help film develop evenly.

24.6 *Stop Bath or Rinse* — After development is complete, the activity of developer remaining in the

emulsion should be neutralized by an acid stop bath or, if this is not possible, by rinsing with vigorous agitation in clear water. Follow the film manufacturer's recommendation of stop bath composition (or length of alternative rinse), time immersed, and life of bath.

24.7 *Fixing* — The films must not touch one another in the fixer. Agitate the hangers vertically for about 10 s and again at the end of the first minute, to ensure uniform and rapid fixation. Keep them in the fixer until fixation is complete (that is, at least twice the clearing time), but not more than 15 min in relatively fresh fixer. Frequent agitation will shorten the time of fixation.

24.8 *Fixer Neutralizing* — The use of a hypo eliminator or fixer neutralizer between fixation and washing may be advantageous. These materials permit a reduction of both time and amount of water necessary for adequate washing. The recommendations of the manufacturers as to preparation, use, and useful life of the baths should be observed rigorously.

24.9 *Washing* — The washing efficiency is a function of wash water, its temperature, and flow, and the film being washed. Generally, washing is very slow below 60°F (16°C). When washing at temperatures above 85°F (30°C), care should be exercised not to leave films in the water too long. The films should be washed in batches without contamination from new film brought over from the fixer. If pressed for capacity, as more films are put in the wash, partially washed film should be moved in the direction of the inlet.

24.9.1 The cascade method of washing uses less water and gives better washing for the same length of time. Divide the wash tank into two sections (may be two tanks). Put the films from the fixer in the outlet section. After partial washing, move the batch of film to the inlet section. This completes the wash in fresh water.

24.9.2 For specific washing recommendations, consult the film manufacturer.

24.10 *Wetting Agent* — Dip the film for approximately 30 s in a wetting agent. This makes water drain evenly off film, which facilitates quick, even drying.

24.11 *Residual Fixer Concentrations* — If the fixing chemicals are not removed adequately from the film, they will in time cause staining or fading of the developed image. Residual fixer concentrations permissible depend upon whether the films are to be kept for commercial purposes (3 to 10 years) or must be of archival quality. Archival quality processing is desirable for all radiographs whenever average relative humidity and temperature are likely to be excessive, as is the case in tropical and subtropical climates. The method of determining residual fixer concentrations may be ascertained by reference to ANSI PH4.8, PH1.28, and PH1.41.

24.12 *Drying* — Drying is a function of (*1*) film (base and emulsion); (*2*) processing (hardness of emulsion after washing, use of wetting agent); and (*3*) drying air (temperature, humidity, flow). Manual drying can vary from still air drying at ambient temperature to as high as 140°F (60°C) with air circulated by a fan. Film manufacturers should again be contacted for recommended drying conditions. Take precaution to tighten film on hangers, so that it cannot touch in the dryer. Too hot a drying temperature at low humidity can result in uneven drying and should be avoided.

25. Testing Developer

25.1 It is desirable to monitor the activity of the radiographic developing solution. This can be done by periodic development of film strips exposed under carefully controlled conditions, to a graded series of radiation intensities or time, or by using a commercially available strip carefully controlled for film speed and latent image fading.

26. Viewing Radiographs

26.1 *Transmission* — The illuminator must provide light of an intensity that will illuminate the average density areas of the radiographs without glare and it must diffuse the light evenly over the viewing area. Commercial fluorescent illuminators are satisfactory for radiographs of moderate density; however, high light intensity illuminators are available for densities up to 3.5 or 4.0. Masks should be available to exclude any extraneous light from the eyes of the viewer when viewing radiographs smaller than the viewing port or to cover low-density areas.

26.2 *Reflection* — Radiographs on a translucent or opaque backing may be viewed by reflected light. It is recommended that the radiograph be viewed under diffuse lighting conditions to prevent excess glare. Optical magnification can be used in certain instances to enhance the interpretation of the image.

27. Viewing Room

27.1 Subdued lighting, rather than total darkness, is preferable in the viewing room. The brightness of the surroundings should be about the same as the area of interest in the radiograph. Room illumination must be so arranged that there are no reflections from the surface of the film under examination.

28. Storage of Processed Radiographs

28.1 Radiographs should be stored using the same care as for any other valuable record.

28.2 Envelopes having an edge seam, rather than a center seam, and joined with a nonhygroscopic adhesive, are preferred, since occasional staining and fading of the image is caused by certain adhesives used in the manufacture of envelopes (see ANSI PH1.53).

PART IV — RECORDS, REPORTS, AND IDENTIFICATION OF ACCEPTED MATERIAL

29. Records

29.1 It is recommended that an X-ray log (a log may consist of a card file, punched card system, a book, or other record) constituting a record of each job performed, be maintained. This record should comprise, initially, a job number (which should appear also on the films), the identification of the parts, material or area radiographed, the date the films are exposed, and a complete record of the radiographic procedure, in sufficient detail so that any radiographic techniques may be duplicated readily. If calibration data, or other records such as card files or procedures, are used to determine the procedure, the log need refer only to the appropriate data or other record. Subsequently, the interpreter's findings and disposition (acceptance or rejection), if any, and his initials, should be entered for each job.

30. Reports

30.1 When written reports of radiographic examinations are required, they should include the following, plus such other items as may be agreed upon:

30.1.1 Identification of parts, material, or area.

30.1.2 Radiographic job number.

30.1.3 Findings and disposition, if any. This information can be obtained directly from the log.

31. Identification of Completed Work

31.1 Whenever radiography is an inspective (rather than investigative) operation whereby material is accepted or rejected, all parts and material that have been accepted should be marked permanently, if possible, with a characteristic identifying symbol which will indicate to subsequent or final inspectors the fact of radiographic acceptance.

31.2 Whenever possible, the completed radiographs should be kept on file for reference. The custody of radiographs and the length of time they are preserved should be agreed upon between the contracting parties.

APPENDIX
(Nonmandatory Information)

X1. USE OF FLUORESCENT SCREENS

X1.1 *Description* — Fluorescent intensifying screens have a cardboard or plastic support coated with a uniform layer of inorganic phosphor (crystalline substance). The support and phosphor are held together by a radiotransparent binding material. Fluorescent screens derive their name from the fact that their phosphor crystals "fluoresce" (emit visible light) when struck by X or gamma radiation. Some phosphors like calcium tungstate ($CaWO_4$) give off blue light while others known as rare earth emit light green.

X1.2 *Purpose and Film Types* — Fluorescent screen exposures are usually much shorter than those made without screens or with lead intensifying screens, because radiographic films generally are more responsive to visible light than to direct X-radiation, gamma radiation, and electrons.

X1.2.1 Films fall into one of two categories: non-screen type film having moderate light response, and screen type film specifically sensitized to have a very high blue or green light response. Fluorescent screens can reduce conventional exposures by as much as 150 times, depending on film type.

X1.3 *Image Quality and Use* — The image quality associated with fluorescent screen exposures is a function of sharpness, mottle, and contrast. Screen sharpness depends on phosphor crystal size, thickness of the crystal layer, and the reflective base coating. Each crystal emits light relative to its size and in all directions thus producing a relative degree of image unsharpness. To minimize this unsharpness, screen to film contact should be as intimate as possible. Mottle adversely affects image quality in two ways. First, a "quantum" mottle is dependent upon the amount of X or gamma radiation actually absorbed by the fluorescent screen, that is, faster screen/film systems lead to greater mottle and poorer image quality. A "structural" mottle, which is a function of crystal size, crystal uniformity, and layer thickness, is minimized by using screens having small, evenly spaced crystals in a thin crystalline layer. Fluorescent screens are highly sensitive to longer wavelength scattered radiation. Consequently, to maximize contrast when this non-image forming radiation is excessive, fluorometallic intensifying screens or fluorescent screens backed by lead screens of appropriate thickness are recommended. Screen technology has seen significant advances in recent years, and today's fluorescent screens have smaller crystal size, more uniform crystal packing, and reduced phosphor thickness. This translates into greater screen/film speed with reduced unsharpness and mottle. These improvements can represent some meaningful benefits for industrial radiography, as indicated by the three examples as follows:

X1.3.1 *Reduced Exposure (Increased Productivity)* — There are instances where prohibitively long exposure times make conventional radiography impractical. An example is the inspection of thick, high atomic number materials with low curie isotopes. Depending on many variables, exposure time may be reduced by factors ranging from 2× to 105× when the appropriate fluorescent screen/film combination is used.

X1.3.2 *Improved Safety Conditions (Field Sites)* — Because fluorescent screens provide reduced exposure, the length of time that non-radiation workers must evacuate a radiographic inspection site can be reduced significantly.

X1.3.3 *Extended Equipment Capability* — Utilizing the speed advantage of fluorescent screens by translating it into reduced energy level. An example is that a 150 kV X-ray tube may do the job of a 300 kV tube, or that iridium 192 may be used in applications normally requiring cobalt 60. It is possible for overall image quality to be better at the lower kV with fluorescent screens than at a higher energy level using lead screens.

01 # STANDARD METHOD FOR CONTROLLING QUALITY OF RADIOGRAPHIC TESTING

SE-142

(Identical with ASTM Specification E 142-92)

DELETED

STANDARD REFERENCE RADIOGRAPHS FOR HEAVY-WALLED [2 to $4^{1}/_{2}$-in. (51 to 114-mm)] STEEL CASTINGS 01

SE-186

(Identical with ASTM Specification E 186-93)

DELETED

01 # STANDARD REFERENCE RADIOGRAPHS FOR APPEARANCES OF RADIOGRAPHIC IMAGES AS CERTAIN PARAMETERS ARE CHANGED

SE-242

(Identical with ASTM Specification E 242-91)

DELETED

STANDARD REFERENCE RADIOGRAPHS FOR HEAVY-WALLED [$4^1/_2$ to 12-in. (114 to 305-mm)] STEEL CASTINGS 01

SE-280

(Identical with ASTM Specification E 280-93)

DELETED

01

STANDARD REFERENCE RADIOGRAPHS FOR STEEL CASTINGS UP TO 2 in. (51 mm) IN THICKNESS

SE-446

(Identical with ASTM Specification E 446-93)

DELETED

STANDARD PRACTICE FOR DESIGN, MANUFACTURE, AND MATERIAL GROUPING CLASSIFICATION OF WIRE IMAGE QUALITY INDICATORS (IQI) USED FOR RADIOLOGY

SE-747

(Identical with ASTM Specification E 747-97)

1. Scope

1.1 This practice covers the design, material grouping classification, and manufacture of wire image quality indicators (IQI) used to indicate the quality of radiologic images.

1.2 This practice is applicable to X-ray and gamma-ray radiology.

1.3 This practice covers the use of wire penetrameters as the controlling image quality indicator for the material thickness range from 6.4 to 152 mm (0.25 to 6.0 in.).

1.4 The values stated in inch-pound units are to be regarded as standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

B 139 Specification for Phosphor Bronze Rod, Bar, and Shapes
B 150 Specification for Aluminum Bronze Rod, Bar, and Shapes
B 161 Specification for Nickel Seamless Pipe and Tube
B 164 Specification for Nickel-Copper Alloy Rod, Bar, and Wire
B 166 Specification for Nickel-Chromium-Iron Alloys (UNS N06600, N06601, and N06690) and Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617) Rod, Bar, and Wire
E 1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiography
E 1316 Terminology for Nondestructive Examinations

3. Terminology

3.1 *Definitions* — The definitions of terms in Terminology E 1316, Section D, relating to gamma and x-radiology, shall apply to the terms used in this practice.

4. Wire IQI Requirements

4.1 The quality of all levels of examination shall be determined by a set of wires conforming to the following requirements:

4.1.1 Wires shall be fabricated from materials or alloys identified or listed in accordance with 7.2. Other materials may be used in accordance with 7.3.

4.1.2 The IQI consists of sets of wires arranged in order of increasing diameter. The diameter sizes specified in Table 1 are established from a consecutive series of numbers taken in general from the ISO/R 10 series. The IQI shall be fabricated in accordance with the requirements specified in Figs. 1 through 8 and

TABLE 1
WIRE IQI SIZES AND WIRE IDENTITY NUMBERS

SET A		SET B	
Wire Diameter, in. (mm)	Wire Identity	Wire Diameter, in. (mm)	Wire Identity
0.0032 (0.08)[A]	1	0.010 (0.25)	6
0.004 (0.1)	2	0.013 (0.33)	7
0.005 (0.13)	3	0.016 (0.4)	8
0.0063 (0.16)	4	0.020 (0.51)	9
0.008 (0.2)	5	0.025 (0.64)	10
0.010 (0.25)	6	0.032 (0.81)	11
SET C		**SET D**	
Wire Diameter, in. (mm)	Wire Identity	Wire Diameter, in. (mm)	Wire Identity
0.032 (0.81)	11	0.10 (2.5)	16
0.040 (1.02)	12	0.126 (3.2)	17
0.050 (1.27)	13	0.160 (4.06)	18
0.063 (1.6)	14	0.20 (5.1)	19
0.080 (2.03)	15	0.25 (6.4)	20
0.100 (2.5)	16	0.32 (8)	21

[A]The 0.0032 wire may be used to establish a special quality level as agreed upon between the purchaser and the supplier.

TABLE 2
WIRE DIAMETER TOLERANCES (mm)

Wire Diameter (d), mm	Tolerance, mm
$0.000 < d \le 0.125$	±0.0025
$0.125 < d \le 0.25$	±0.005
$0.25 < d \le 0.5$	±0.01
$0.50 < d \le 1.6$	±0.02
$1.6 < d \le 4$	±0.03
$4.0 < d \le 8$	±0.05

TABLE 3
WIRE DIAMETER TOLERANCES (in.)

Wire Diameter (d), in.	Tolerance, in.
$0.000 < d \le 0.005$	±0.0001
$0.005 < d \le 0.010$	±0.0002
$0.010 < d \le 0.020$	±0.0004
$0.020 < d \le 0.063$	±0.0008
$0.063 < d \le 0.160$	±0.0012
$0.160 < d \le 0.320$	±0.0020

Tables 1, 2, and 3. IQIs previously manufactured to the requirements of Annex A1 may be used as an alternate provided all other requirements of this practice are met.

4.1.3 Image quality indicator (IQI) designs other than those shown in Figs. 1 through 8 and Annex A1 are permitted by contractual agreement. If an IQI set as listed in Table 1 or Annex A1 is modified in size, it must contain the grade number, set identity, and essential wire. It must also contain two additional wires that are the next size larger and the next size smaller as specified in the applicable set listed in Table 1.

4.1.4 Each set must be identified using letters and numbers made of industrial grade lead or of a material of similar radiographic density. Identification shall be as shown in Figs. 1 through 8 or Annex A1, unless otherwise specified by contractual agreement.

5. Image Quality Indicator (IQI) Procurement

5.1 When selecting IQIs for procurement, the following factors should be considered:

5.1.1 Determine the alloy group(s) of the material to be examined.

5.1.2 Determine the thickness or thickness range of the material(s) to be examined.

5.1.3 Select the applicable IQIs that represent the required IQI thickness(s) and alloy(s).

6. Image Quality Levels

6.1 The quality level required using wire penetrameters shall be equivalent to the 2-2T level of Practice E 1025 for hole-type IQIs unless a higher or lower quality level is agreed upon between purchaser and supplier. Table 4 provides a list of various hole-type IQIs and the diameter of wires of corresponding equivalent penetrameter sensitivity (EPS) with the applicable 1T, 2T, and 4T holes in the IQI. This table can be used for determining 1T, 2T, and 4T quality levels. Appendix X1 gives the equation for calculating other equivalencies if needed.

6.2 In specifying quality levels, the contract, purchase order, product specification, or drawing should clearly indicate the thickness of material to which the quality level applies. Careful consideration of required quality levels is particularly important.

7. Material Groups

7.1 *General:*

7.1.1 Materials have been designated in eight groups based on their radiographic absorption character-

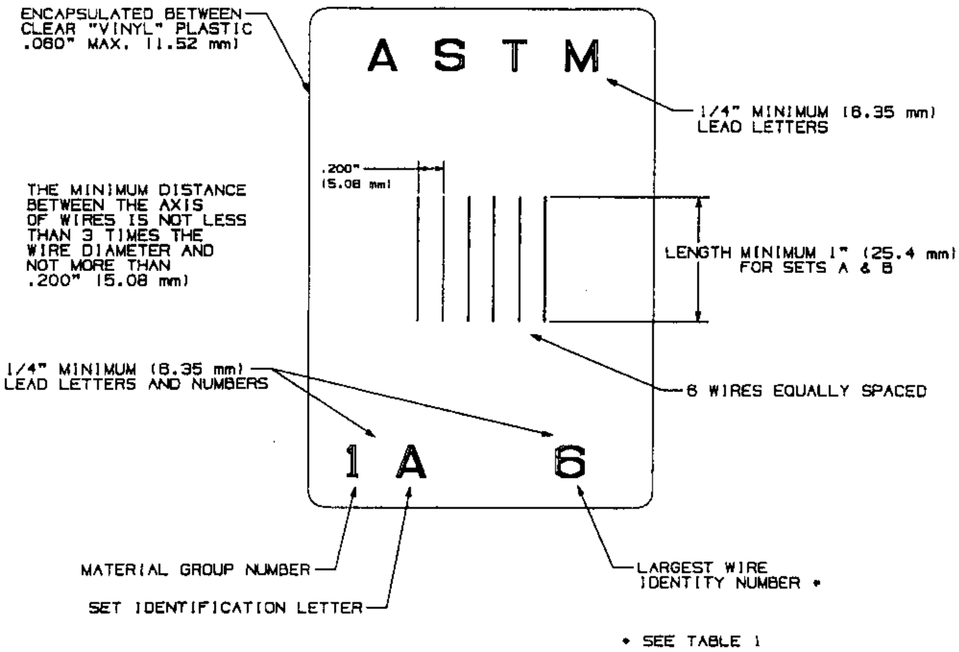


FIG. 1 SET A/ALTERNATE 1

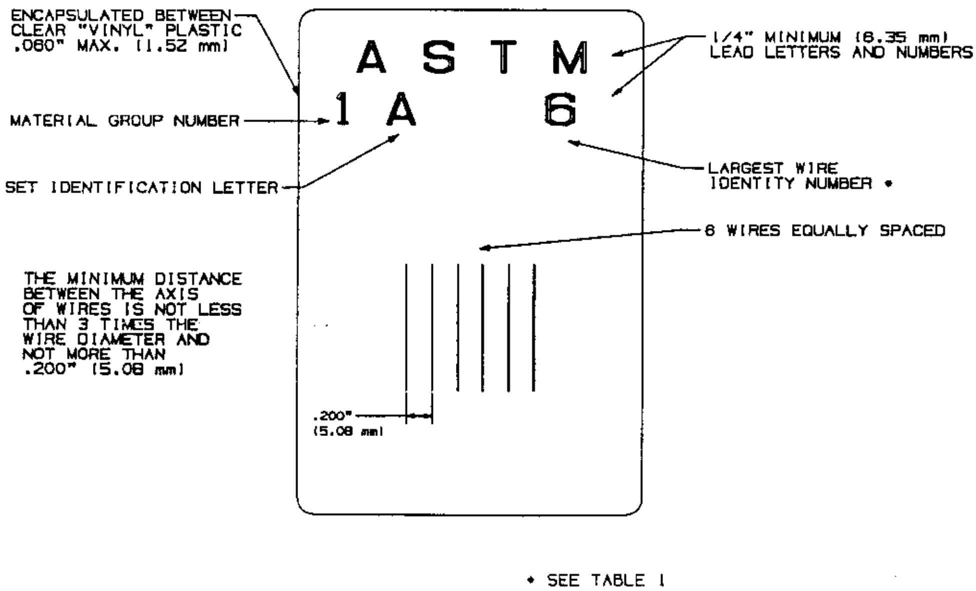


FIG. 2 SET A/ALTERNATE 2

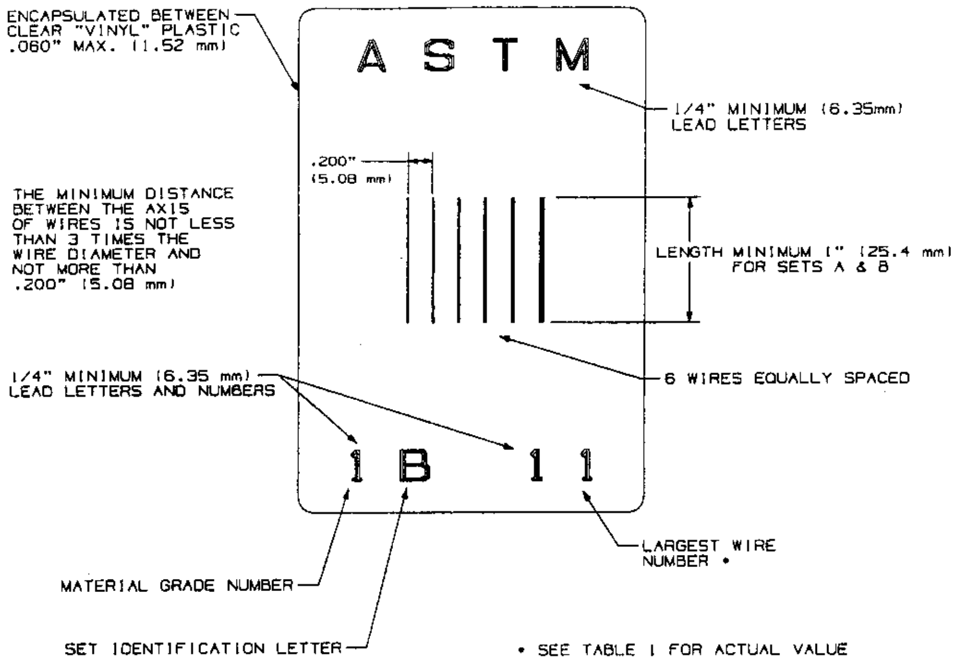


FIG. 3 SET B/ALTERNATE 1

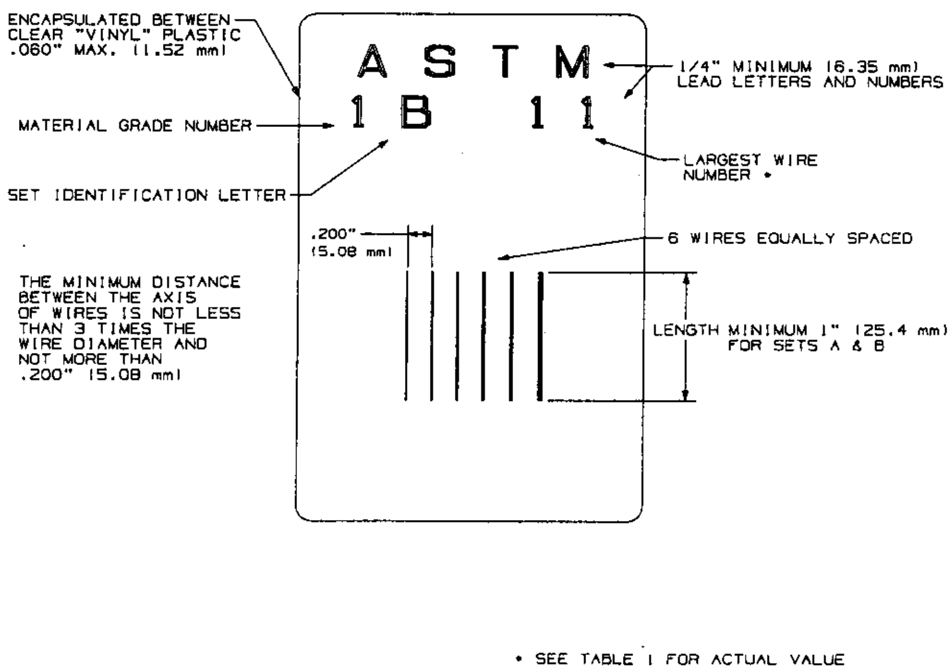


FIG. 4 SET B/ALTERNATE 2

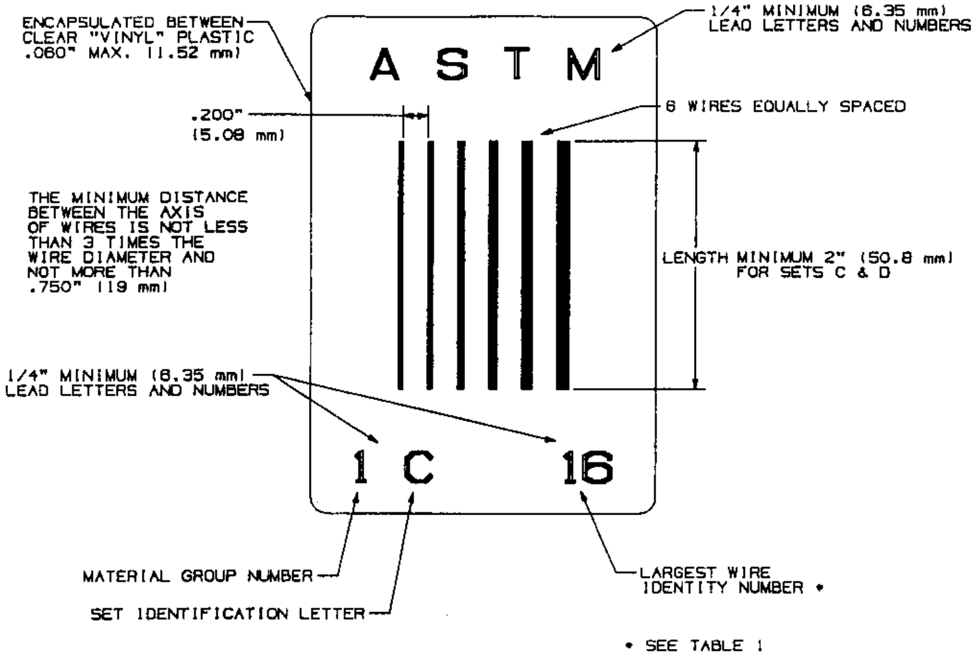


FIG. 5 SET C/ALTERNATE 1

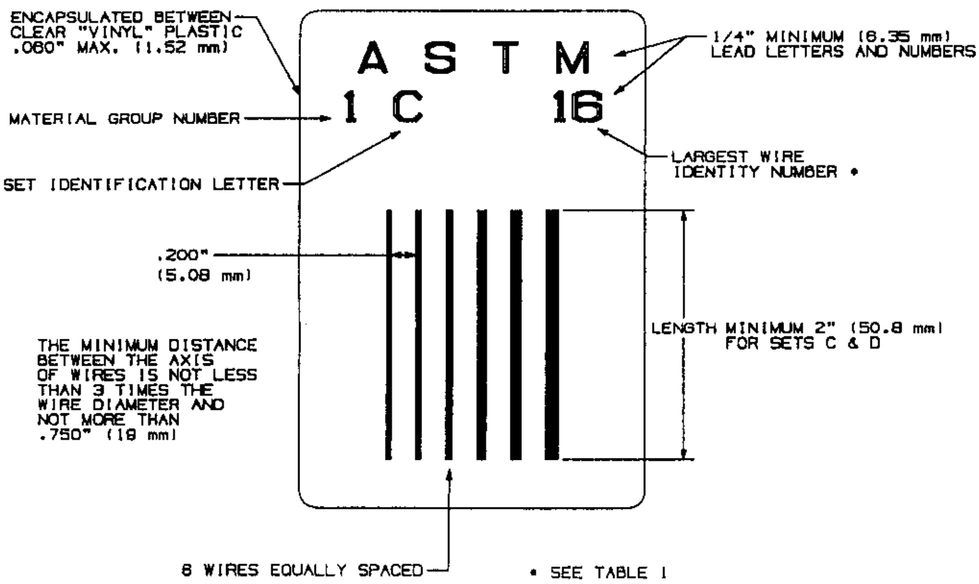


FIG. 6 SET C/ALTERNATE 2

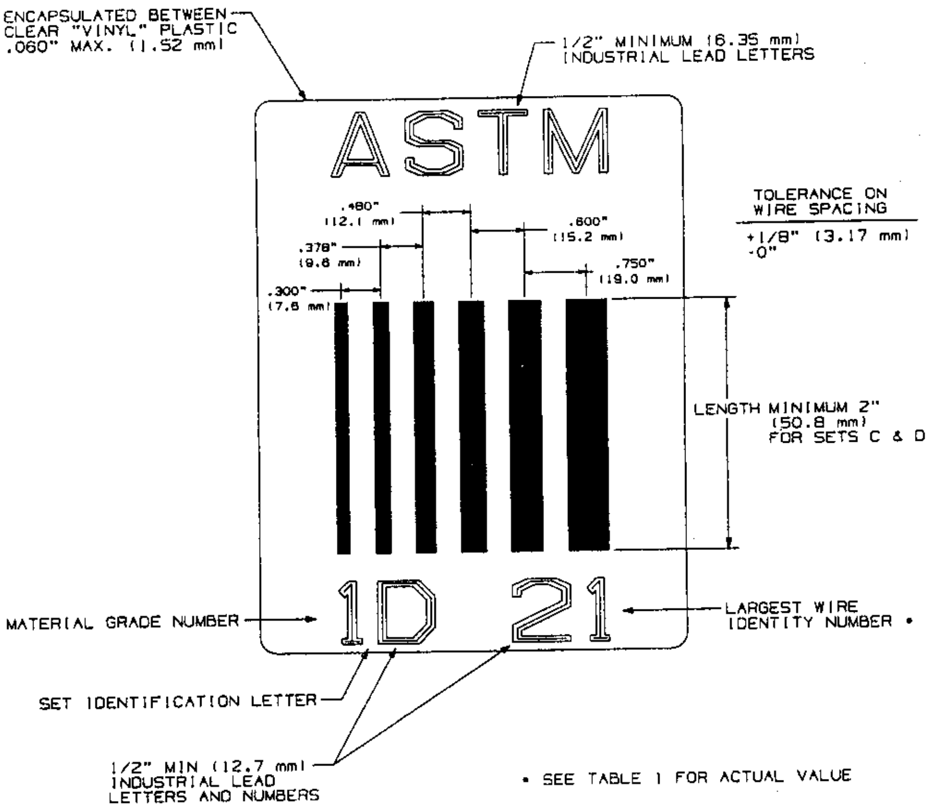


FIG. 7 SET D/ALTERNATE 1

istics: groups 03, 02, and 01 for light metals and groups 1 through 5 for heavy metals.

7.1.2 The light metal groups, magnesium (Mg), aluminum (Al), and titanium (Ti), are identified 03, 02, and 01 respectively, for their predominant alloying constituent. The materials are listed in order of increasing radiation absorption.

7.1.3 The heavy metal groups, steel, copper-base, nickel-base, and kindred alloys, are identified 1 through 5. The materials increase in radiation absorption with increasing numerical designation.

7.1.4 Common trade names or alloy designations have been used for clarification of the pertinent materials.

7.1.5 The materials from which the IQI for the group are to be made are designated in each case and these IQIs are applicable for all materials listed in that group. In addition, any group IQI may be used for any material with a higher group number, provided the applicable quality level is maintained.

7.2 *Materials Groups:*

7.2.1 *Materials Group 01:*

7.2.1.1 Image quality indicators (IQIs) shall be made of titanium or titanium shall be the predominant alloying constituent.

7.2.1.2 Use on all alloys of which titanium is the predominant alloying constituent.

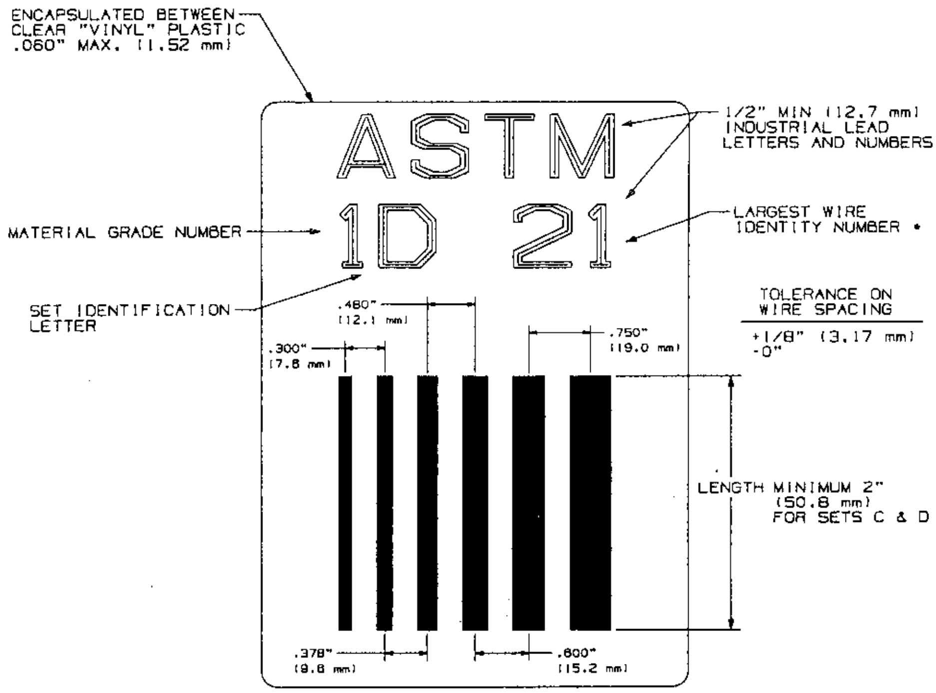
7.2.2 *Materials Group 02:*

7.2.2.1 Image quality indicators (IQIs) shall be made of aluminum or aluminum shall be the predominant alloying constituent.

7.2.2.2 Use on all alloys of which aluminum is the predominant alloying constituent.

7.2.3 *Materials Group 03:*

7.2.3.1 Image quality indicators (IQIs) shall be made of magnesium or magnesium shall be the predominant alloying constituent.



* SEE TABLE 1 FOR ACTUAL VALUE

FIG. 8 SET D/ALTERNATE 2

7.2.3.2 Use on all alloys of which magnesium is the predominant alloying constituent.

7.2.4 *Materials Group 1:*

7.2.4.1 Image quality indicators (IQIs) shall be made of carbon steel or Type 300 series stainless steel.

7.2.4.2 Use on all carbon steel, low-alloy steels, stainless steels, and manganese-nickel-aluminum bronze (Superston).

7.2.5 *Materials Group 2:*

7.2.5.1 Image quality indicators (IQIs) shall be made of aluminum bronze (Alloy No. 623 of Specification B 150) or equivalent, or nickel-aluminum bronze (Alloy No. 630 of Specification B 150) or equivalent.

7.2.5.2 Use on all aluminum bronzes and all nickel-aluminum bronzes.

7.2.6 *Materials Group 3:*

7.2.6.1 Image quality indicators (IQIs) shall be made of nickel-chromium-iron alloy (UNS No. N06600) (Inconel). (See Specification B 166.)

7.2.6.2 Use on nickel-chromium-iron alloy and 18% nickel-maraging steel.

7.2.7 *Materials Group 4:*

7.2.7.1 Image quality indicators (IQIs) shall be made of 70 to 30 nickel-copper alloy (Monel) (Class A or B of Specification B 164) or equivalent, or 70 to 30 copper-nickel alloy (Alloy G of Specification B 161) or equivalent.

7.2.7.2 Use on nickel, copper, all nickel-copper series, or copper-nickel series of alloys, and all brasses (copper-zinc alloys). Group 4 IQIs may include the leaded brasses since leaded brass increases in attenuation with increase in lead content. This would be equivalent to using a lower group IQI.

7.2.8 *Materials Group 5:*

7.2.8.1 Image quality indicators (IQIs) shall be made of tin bronze (Alloy D of Specification B 139).

7.2.8.2 Use on tin bronzes including gun-metal and valve bronze, or leaded-tin bronze of higher lead content than valve bronze. Group 5 IQIs may include

TABLE 4
WIRE SIZES EQUIVALENT TO CORRESPONDING 1T, 2T, AND 4T HOLES IN VARIOUS HOLE TYPE PLAQUES

Plaque Thickness, in. (mm)	Plaque IQI Identification Number	Diameter of wire with EPS of hole in plaque, in. (mm) 1T	2T	4T
0.005 (0.13)	5		0.0038 (0.09)	0.006 (0.15)
0.006 (0.16)	6		0.004 (0.10)	0.0067 (0.18)
0.008 (0.20)	8	0.0032 (0.08)	0.005 (0.13)	0.008 (0.20)
0.009 (0.23)	9	0.0035 (0.09)	0.0056 (0.14)	0.009 (0.23)
0.010 (0.25)	10	0.004 (0.10)	0.006 (0.15)	0.010 (0.25)
0.012 (0.30)	12	0.005 (0.13)	0.008 (0.20)	0.012 (0.28)
0.015 (0.38)	15	0.0065 (0.16)	0.010 (0.25)	0.016 (0.41)
0.017 (0.43)	17	0.0076 (0.19)	0.012 (0.28)	0.020 (0.51)
0.020 (0.51)	20	0.010 (0.25)	0.015 (0.38)	0.025 (0.63)
0.025 (0.64)	25	0.013 (0.33)	0.020 (0.51)	0.032 (0.81)
0.030 (0.76)	30	0.016 (0.41)	0.025 (0.63)	0.040 (1.02)
0.035 (0.89)	35	0.020 (0.51)	0.032 (0.81)	0.050 (1.27)
0.040 (1.02)	40	0.025 (0.63)	0.040 (1.02)	0.063 (1.57)
0.050 (1.27)	50	0.032 (0.81)	0.050 (1.27)	0.080 (2.03)
0.060 (1.52)	60	0.040 (1.02)	0.063 (1.57)	0.100 (2.54)
0.070 (1.78)	70	0.050 (1.27)	0.080 (2.03)	0.126 (3.20)
0.080 (2.03)	80	0.063 (1.57)	0.100 (2.54)	0.160 (4.06)
0.100 (2.5)	100	0.080 (2.03)	0.126 (3.20)	0.200 (5.08)
0.120 (3.05)	120	0.100 (2.54)	0.160 (4.06)	0.250 (6.35)
0.140 (3.56)	140	0.126 (3.20)	0.200 (5.08)	0.320 (8.13)
0.160 (4.06)	160	0.160 (4.06)	0.250 (6.35)	
0.200 (5.08)	200	0.200 (5.08)	0.320 (8.13)	
0.240 (6.10)	240	0.250 (6.35)		
0.280 (7.11)	280	0.320 (8.13)		

bronze of higher lead content since leaded bronze increases in attenuation with increase in lead content. This would be equivalent to using a lower group IQI.

NOTE 1 — In developing the eight listed materials groups, a number of other trade names or other nominal alloy designations were evaluated. For the purpose of making this practice as useful as possible, these materials are listed and categorized, by group, as follows:

(1) Group 2 — Haynes Alloy IN-100.

(2) Group 3 — Haynes Alloy No. 713C, Hastelloy D, G. E. Alloy SEL, Haynes Stellite Alloy No. 21, GMR-235 Alloy, Haynes Alloy No. 93, Inconel X, Inconel 718, and Haynes Stellite Alloy No. S-816.

(3) Group 4 — Hastelloy Alloy F, Hastelloy Alloy X, and Multimeter Alloy Rene 41.

(4) Group 5 — Alloys in order of increasing attenuation: Hastelloy Alloy B, Hastelloy Alloy C, Haynes Stellite Alloy No. 31, Thetaloy, Haynes Stellite No. 3, Haynes Alloy No. 25. Image quality indicators (IQIs) of any of these materials are considered applicable for the materials that follow it.

NOTE 2 — The committee formulating these recommendations recommends other materials may be added to the materials groups listed as the need arises or as more information is gained, or that additional materials groups may be added.

7.3 *Method for Other Materials:*

7.3.1 For materials not herein covered, IQIs of the same materials, or any other material, may be used if the following requirements are met. Two blocks of equal thickness, one of the material to be examined (production material) and one of the IQI material, shall be radiographed on one film by one exposure at the lowest energy level to be used for production. Transmission densitometer measurements of the radiographic image of each material shall be made. The density of each image shall be between 2.0 and 4.0. If the image density of the IQI material is within 1.00 to 1.15 times (–0% to +15%) the image density of the production material, IQIs made of that IQI material may be used in radiography of that production material. The percentage figure is based on the radiographic density of the IQI material.

7.3.2 It shall always be permissible to use IQIs of similar composition as the material being examined.

8. Image Quality Indicator (IQI) Certification

8.1 Documents shall be provided by the IQI manufacturer attesting to the following:

8.1.1 IQI identification alternate, if used.

8.1.2 Material type.

8.1.3 Conformance to specified tolerances for dimensional values.

8.1.4 ASTM standard designation, for example, ASTM E 747 — (year designation) used for manufacturing.

9. Precision and Bias

9.1 *Precision and Bias* — No statement is made about the precision or bias for indicating the quality of images since the results merely state whether there is conformance to the criteria for success specified in this practice.

10. Keywords

10.1 density; image quality level; IQI; radiologic; radiology; x-ray and gamma radiation

ANNEX

(Mandatory Information)

A1. ALTERNATE IQI IDENTIFICATION

A1.1 The use of IQIs with identifications as shown in Figs. A1.1 through A1.9 and as listed in Table A1.1 is permitted as an acceptable alternate provided all other requirements of Practice E 747 are satisfied.

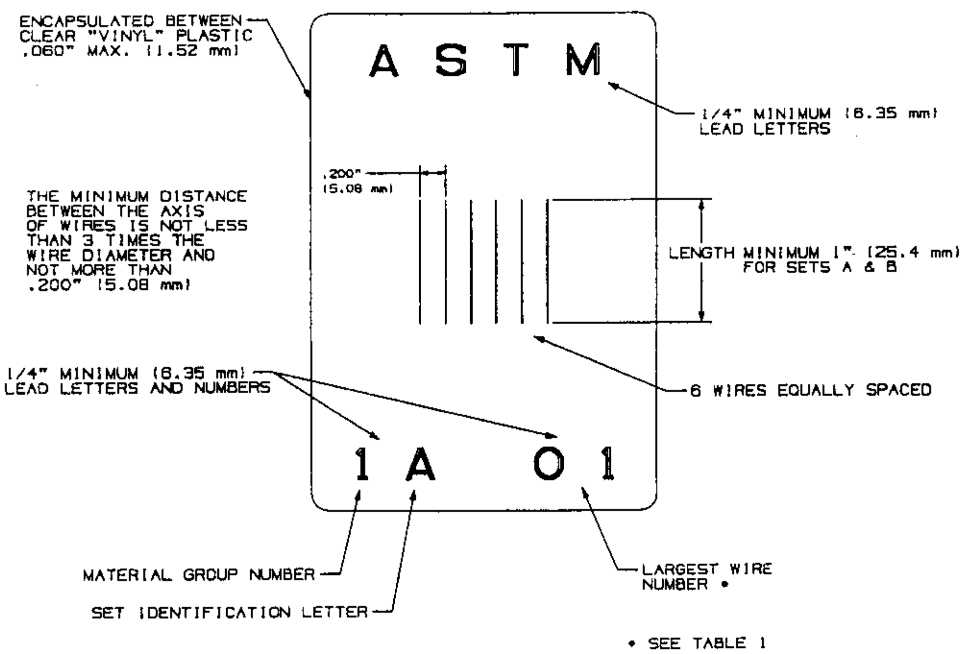


FIG. A1.1 SET A/ALTERNATE 1

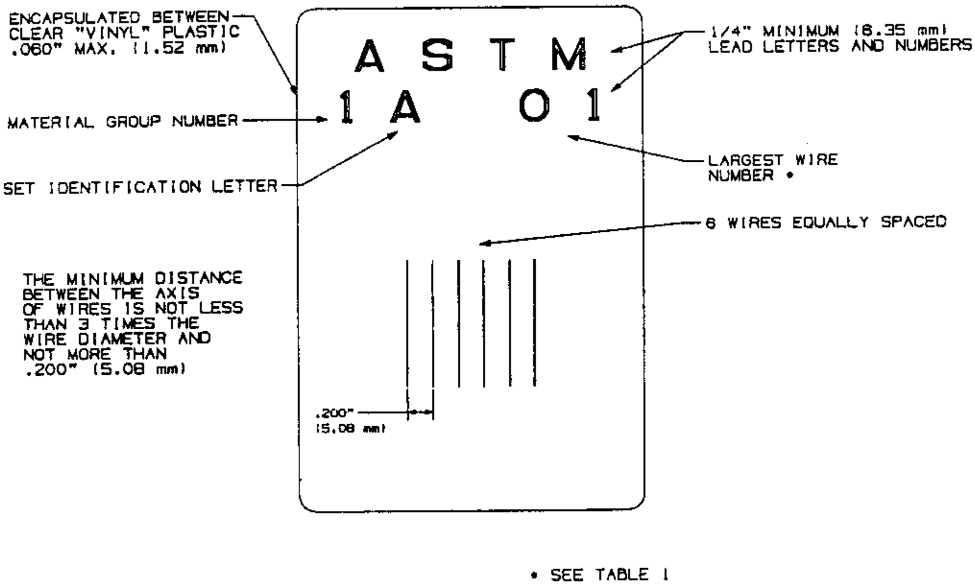


FIG. A1.2 SET A/ALTERNATE 2

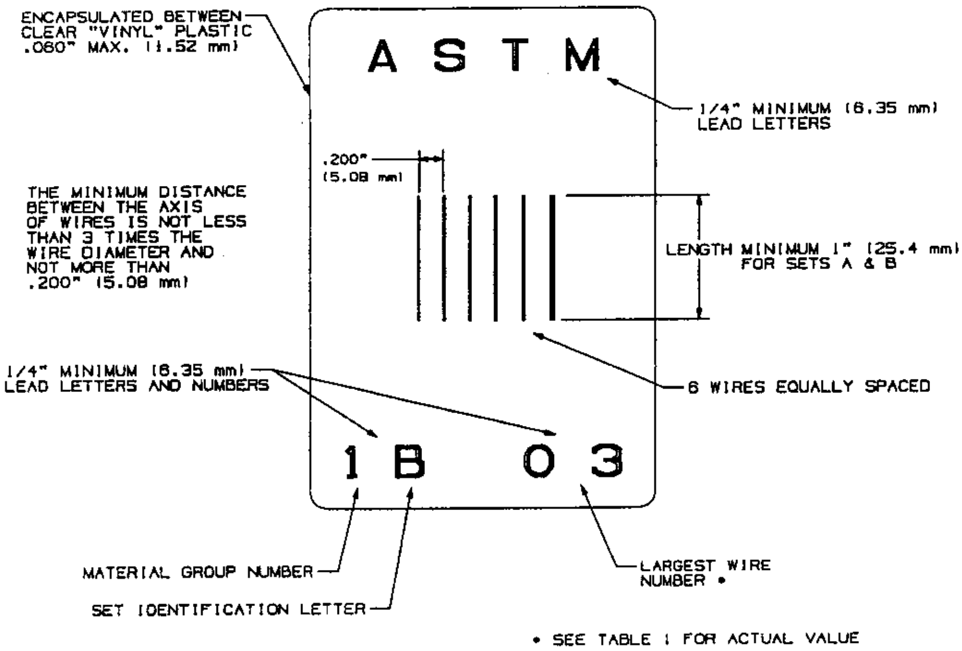


FIG. A1.3 SET B/ALTERNATE 1

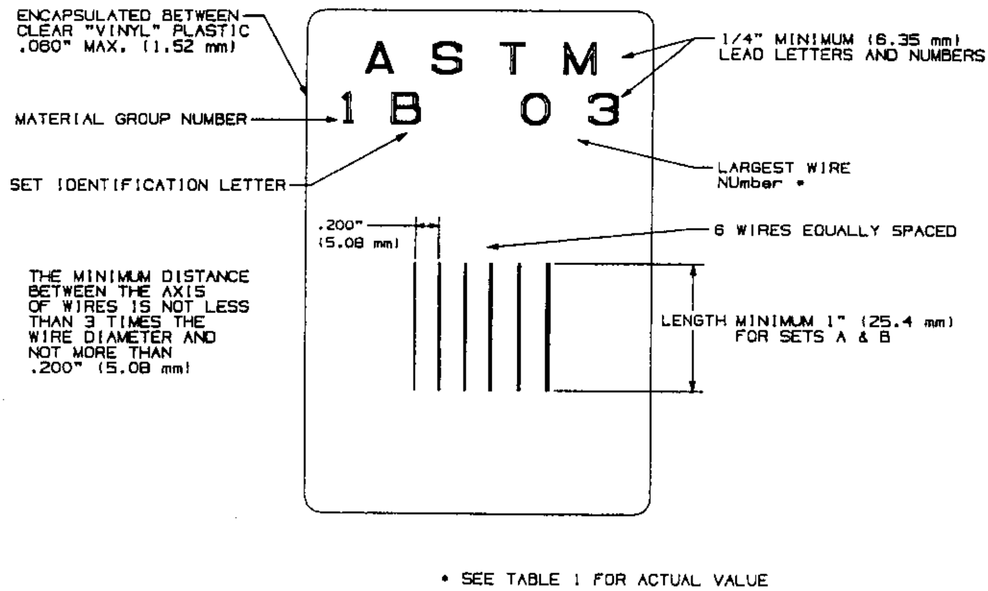


FIG. A1.4 SET B/ALTERNATE 2

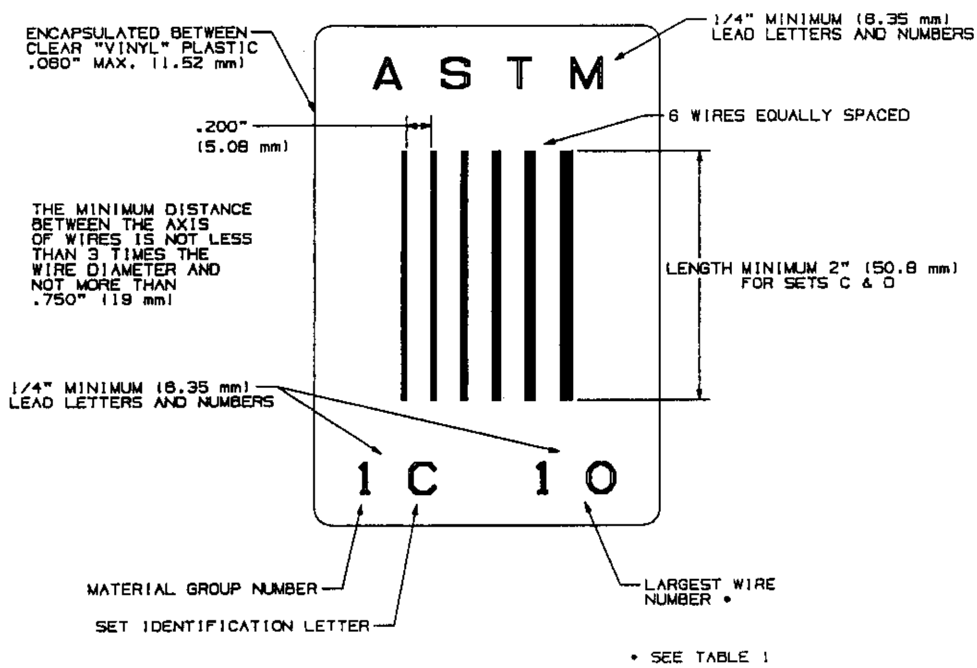


FIG. A1.5 SET C/ALTERNATE 1

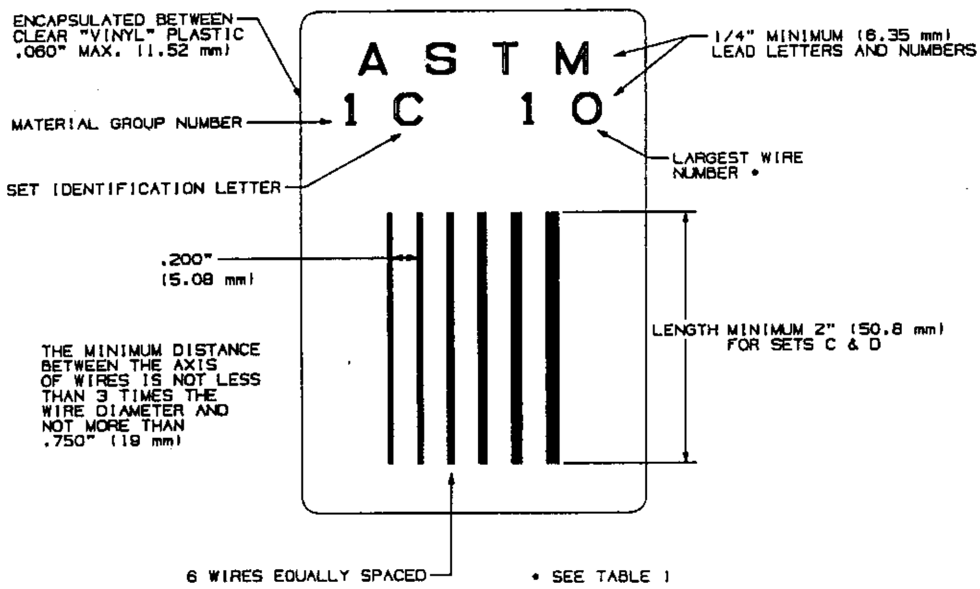


FIG. A1.6 SET C/ALTERNATE 2

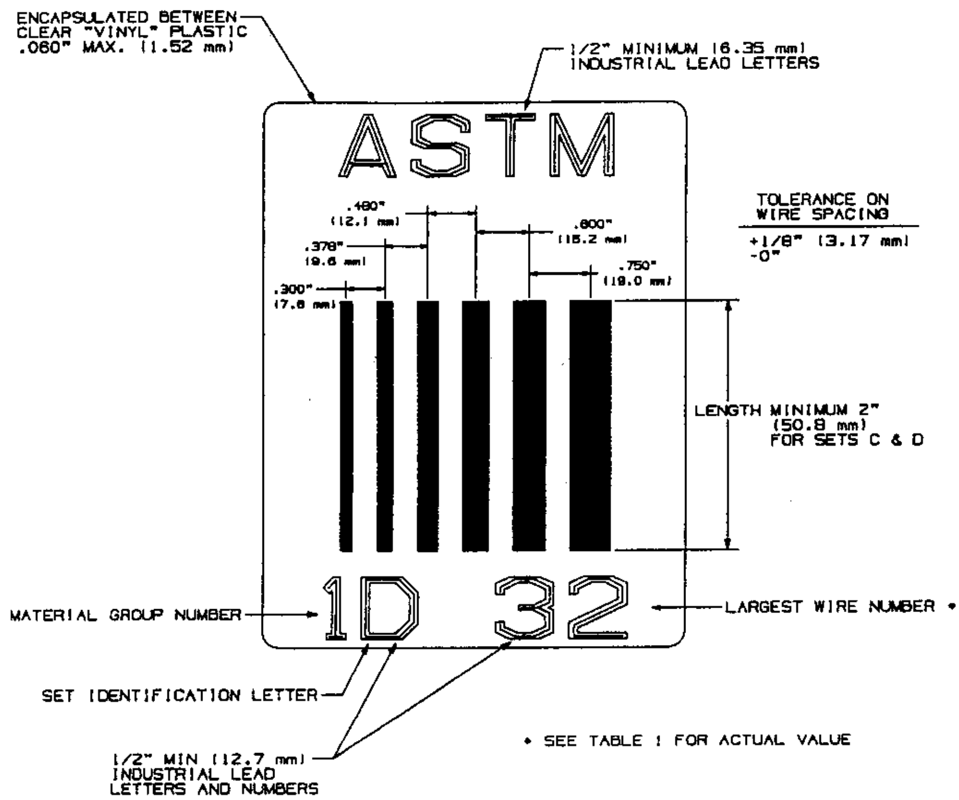


FIG. A1.7 SET D/ALTERNATE 1

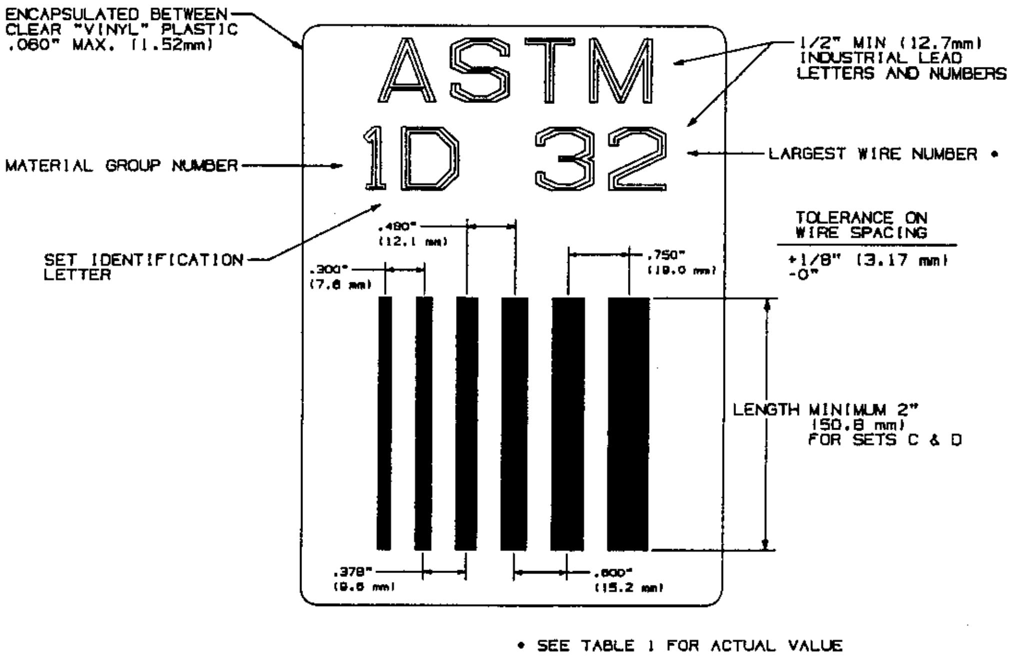
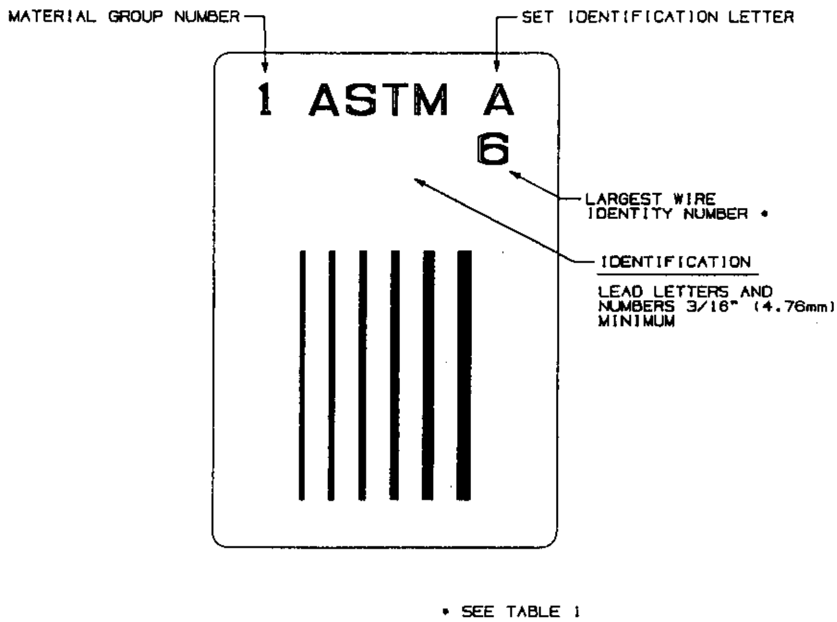


FIG. A1.8 SET D/ALTERNATE 2



NOTE—All other IQI requirements as shown on Figs. 1 through 8 or Figs. A1.1 through A1.8 apply.

FIG. A1.9 ALTERNATE IDENTIFICATION LOCATIONS AND LETTER, NUMBER SIZE-TYPICAL ALL SETS (A, B, C, D)

TABLE A1.1
PENETRAMETER SIZES WIRE DIAMETER, in. (mm)

SET A	SET B
0.0032 (0.08)[A]	0.010 (0.25)
0.004 (0.1)	0.013 (0.33)
0.005 (0.13)	0.016 (0.41)
0.0063 (0.16)	0.020 (0.51)
0.008 (0.2)	0.025 (0.64)
0.010 (0.25)	0.032 (0.81)
SET C	**SET D**
0.032 (0.81)	0.100 (2.5)
0.040 (1.02)	0.126 (3.2)
0.050 (1.27)	0.160 (4.06)
0.063 (1.6)	0.20 (5.1)
0.080 (2.03)	0.25 (6.4)
0.100 (2.5)	0.32 (0.81)

[A] The 0.0032 wire may be used to establish a special quality level as agreed upon between the purchaser and the supplier.

APPENDIX

(Nonmandatory Information)

X1. CALCULATING OTHER EQUIVALENTS

X1.1 The equation to determine the equivalencies between wire and (hole type) IQIs is as follows:

$$F^3 d^3 l = T^2 H^2 (\pi/4)$$

where:

F = form factor for wire, 0.79,
d = wire diameter, in. (mm),
l = effective length of wire, 0.3 in. (7.6 mm),
T = plaque thickness, in. (mm), and
H = diameter of hole, in. (mm).

X1.2 It should be noted that the wire and plaque (hole type) IQI sensitivities cannot be related by a fixed constant.

X1.3 Figures X1.1 and X1.2 are conversion charts for hole type IQI's containing 1T and 2T holes to wires. The sensitivities are given as a percentage of the specimen thickness.

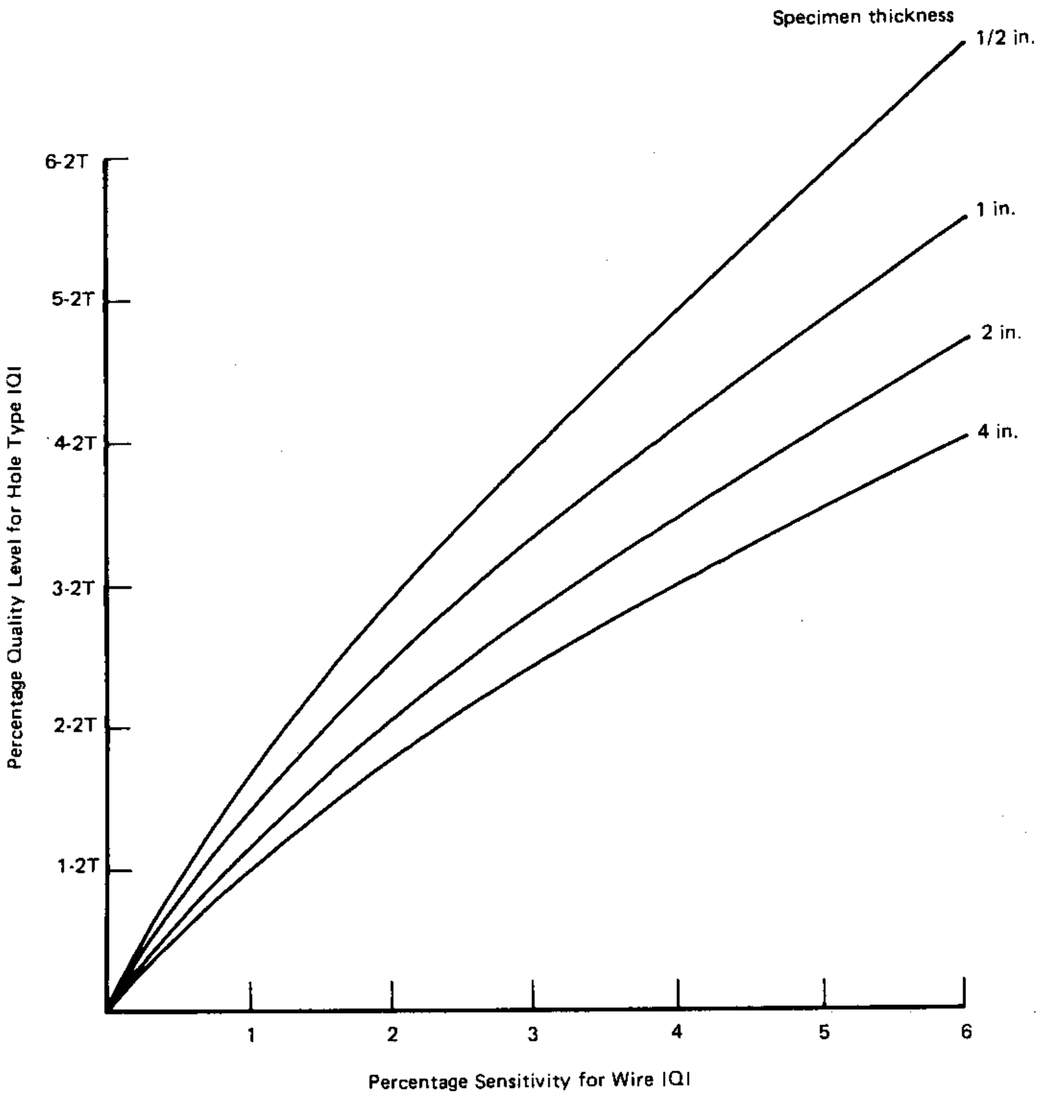


FIG. X1.1 CONVERSION CHART FOR 2-T QUALITY LEVEL HOLES TO PERCENTAGE WIRE SENSITIVITY

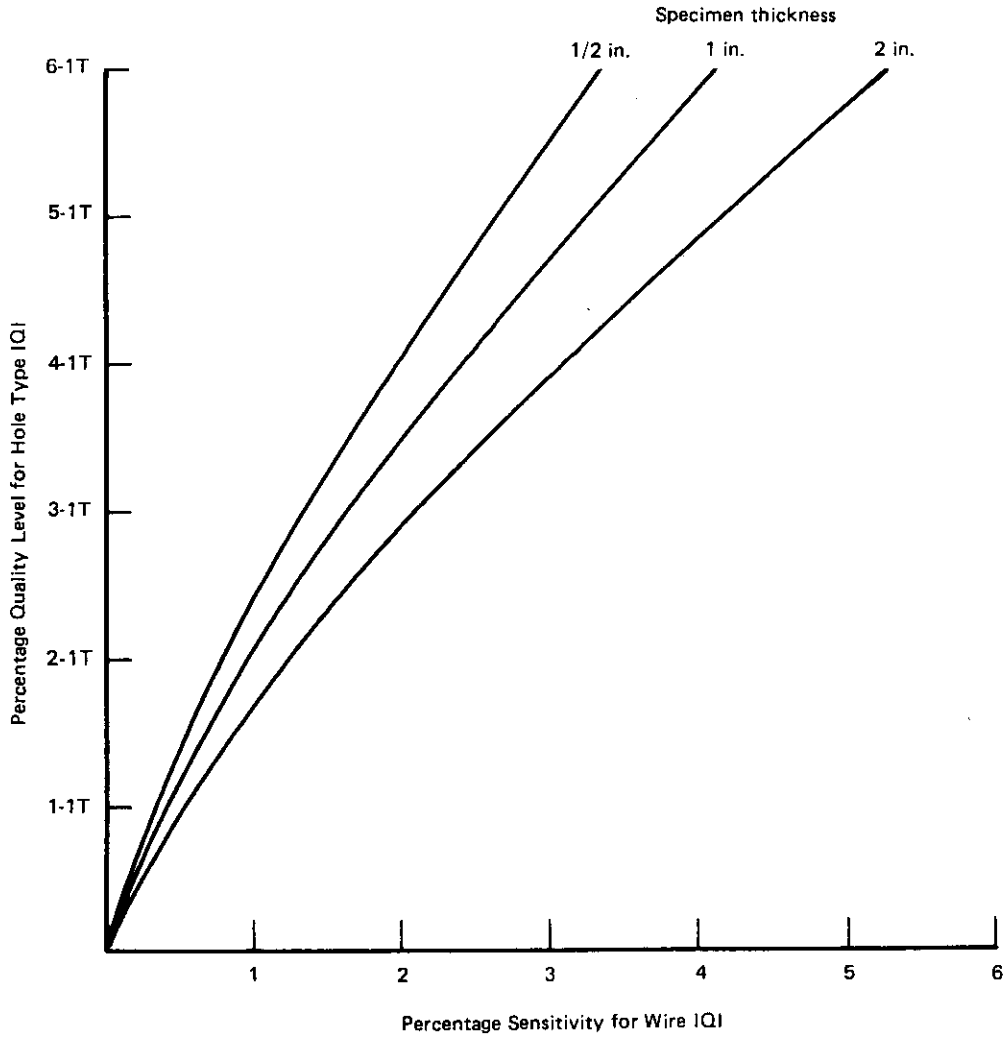


FIG. X1.2 CONVERSION CHART FOR 1-T QUALITY LEVEL HOLES TO PERCENTAGE WIRE SENSITIVITY

STANDARD GUIDE FOR CONTROLLING THE QUALITY OF INDUSTRIAL RADIOGRAPHIC FILM PROCESSING

SE-999

(Identical with ASTM Specification E 999-95)

1. Scope

1.1 This guide establishes guidelines that may be used for the control and maintenance of industrial radiographic film processing equipment and materials. Effective use of these guidelines aid in controlling the consistency and quality of industrial radiographic film processing.

1.2 Use of this guide is limited to the processing of films for industrial radiography. This guide includes procedures for wet-chemical processes and dry processing techniques.

1.3 The necessity of applying specific control procedures such as those described in this guide is dependent, to a certain extent, on the degree to which a facility adheres to good processing practices as a matter of routine procedure.

1.4 If a nondestructive testing agency, as described in Practice E 543, is used to perform the examination, the testing agency shall meet the requirements of Practice E 543.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For more specific safety precautionary statements, see 4.2.3, 4.3.1, 6.1.2, and 6.1.9.

2. Referenced Documents

2.1 *ASTM Standard:*

E 94 Guide for Radiographic Testing

E 543 Practice for Determining the Qualification of Nondestructive Testing Agencies

E 1316 Terminology for Nondestructive Examinations

2.2 *ANSI Standard:*

ANSI PH 4.8 Methylene Blue Method for Measuring Thiosulfate and Silver Densitometric Method for Measuring Residual Chemicals in Films, Plates, and Papers

3. Terminology

3.1 *Definitions* — For definitions of terms used in this guide, see Terminology E 1316.

4. Significance and Use

4.1 The provisions in this guide are intended to control the reliability or quality of the image development process only and are not intended for controlling the acceptability or quality of industrial radiographic films or of the materials or products radiographed. It is further intended that this guide be used as an adjunct to and not a replacement for Guide E 94.

5. Chemical Mixing for Manual and Automatic Processes

5.1 Any equipment that comes in contact with processing solutions should be made of glass, hard rubber, polyethylene, PVC, enameled steel, stainless steel, or

other chemically inert materials. This includes materials such as plumbing, mixing impellers, and the cores of filter cartridges. Do not allow materials such as tin, copper, steel, brass, aluminum, or zinc to come into contact with processing solutions. These materials can cause solution contamination that may result in film fogging or rapid oxidation.

5.2 *Mixing Chemicals:*

5.2.1 Do not mix powdered chemicals in processor tanks, since undissolved particles may be left in the square corners of the tank. Mix solutions in separate containers made from materials specified in 4.1.

5.2.2 Carefully follow the manufacturer's package directions or formulas for mixing the chemicals. Start with the correct volume of water at the temperature specified in the instructions, and add chemicals in the order listed.

5.2.3 Caution — During the mixing and use of photographic processing chemicals, be sure to observe all precautionary information on chemical containers and in instructions.

5.3 *Contamination of Solutions:*

5.3.1 Thoroughly clean all mixing equipment immediately after use to avoid contamination when the next solution is mixed. When mixing fixer from powder, make sure to add the powder carefully to the water in the mixing tank so that fixer dust does not get into other processing solutions. When mixing any chemical, protect nearby tank solutions with floating lids and dust covers. The use of a vent hood is recommended as a safety precaution.

5.3.2 The water supply should either be distilled or filtered so that it is clean and sediment-free.

5.3.3 If large tanks are used for mixing, carefully mark the volume levels to be certain that volumes are correct.

5.3.4 Use of impeller-type mixers provides rapid, thorough mixing but take care to position the impeller at such an angle and depth that the minimum amount of air will be drawn into the solution. Over-mixing of the solutions can cause oxidation, especially with developers, and should be avoided. Rinse the shaft, impeller, and mounting clamp with water after use.

5.4 *Maintaining Equipment:*

5.4.1 Immediately clean all mixing equipment after use.

5.4.2 In addition to cleaning equipment immediately after use, wash any mixing apparatus that has been idle for a long period of time to eliminate dust and dirt that may have accumulated.

5.4.3 Processing hangers and tanks should be free of corrosion and chemical deposits. Encrusted deposits that accumulate in tanks, trays, and processing equipment and that are difficult to remove by conventional cleaning can be removed by using the specially formulated cleaning agents recommended by the chemical or equipment manufacturer.

6. Storage of Solutions

6.1 *In Original Containers* — Follow the manufacturer's storage and capacity recommendations packaged with the chemicals. Do not use chemicals that have been stored longer than recommended.

6.2 *In Replenisher or Process Tanks* — Wherever possible, protect solutions in tanks with floating lids and dust covers. In addition to preventing contaminants from entering solutions, floating lids and dust covers help to minimize oxidation and evaporation from the surface of the solutions. Evaporation can concentrate solutions and reduce temperatures causing precipitation of some of the solution constituents.

6.2.1 Store replenisher solutions for small volume operations in airtight containers. The caps of these containers should be free of corrosion and foreign particles that could prevent a tight fit.

6.3 *Temperature* — Store all solutions at normal room temperature, between 40 to 80°F (4 to 27°C). Storing solutions, particularly developer, at elevated temperatures can produce rapid oxidation resulting in loss of activity and a tendency to stain the film. Storage at too low a temperature can cause some solution to crystallize, and the crystals may not redissolve even with heating and stirring.

6.4 *Deterioration* — Photographic chemicals can deteriorate either with age or with usage. Carefully follow the manufacturer's recommendations for storage life and useful capacity. Discard processing solutions when the recommended number of films have been processed or the recommended storage life of the prepared solution has been reached, whichever occurs first.

6.5 *Contamination:*

6.5.1 Liquid chemicals are provided in containers with tight-fitting tops. To avoid contamination, never interchange the top of one container with another.

6.5.2 Clearly label replenisher storage tanks with the solution that they contain and use that container only with that solution. If more than one developer or one fixer formulation are being used, a separate replenisher tank should be dedicated to each chemical. Differences in developer or fixer formulations from one manufacturer to another may contaminate similar solutions.

7. Processing

7.1 *Manual Processing:*

7.1.1 Follow the temperature recommendations from the film or solution manufacturer and check thermometers. Check thermometers and temperature-controlling devices periodically to be sure that the process temperatures are correct. Process temperatures should be checked at least once per shift. Keep the temperature of the stop (if used), fixer, and wash water within ±5°F (±3°C) of the developer temperature.

7.1.2 Caution — An unprotected mercury-filled thermometer should never be used for photographic processing applications because accidental breakage could result in serious mercury contamination of the process.

7.1.3 Control of processing solution temperature and immersion time relationships are instrumental considerations when establishing a processing procedure that will consistently produce radiographs of desired density and quality. The actual time and temperature relationships established are governed largely by the industrial radiographic films and chemicals used and should be within the limits of the manufacturer's recommendations for those materials. When determining the immersion time for each solution, assure that the draining time is included. Draining time should be consistent from solution to solution. The darkroom timers used should be periodically checked for accuracy.

7.1.4 Agitate at specified intervals for the times recommended by the film or solution manufacturer.

7.1.5 During film processing certain constituents within the solutions undergo chemical transformations that render them useless for further processing functions. In addition, some solution adheres to the film and is carried on into the next solution during processing. In order to compensate for these reductions in solution activity and volume, add replenishment solution. The volume of replenishment necessary is governed primarily by the number, size, and density of films processed. Manufacturer's recommendations for replenishment are based on these criteria and will generally provide suitable results for the expected life of the solution. In any case, maintain solution levels to ensure complete immersion of the film.

7.1.6 The functional constituents in a freshly mixed developer solution tend to overreact on the initial films processed and may develop unexposed areas on the films. For this reason, measures should be taken to stabilize the activity of the solution and thus *season* the developer. This can be accomplished by the use of developer starter solution or by processing a series of *seasoning films* (see Note 1) in the freshly mixed solution. When using developer starter solution follow the manufacturer's recommendations for the product. When using seasoning films expose the films with visible light and then develop these films in the solution to be seasoned. Use three 14 by 17-in. (35 by 43-cm) films, or equivalent, per gallon (3.8 L) of developer.

NOTE 1 — Seasoning films may be new films or films that may not be generally suitable for production purposes due to excessive gross fog (base plus fog) density, expiration of shelf life, or other reasons.

7.1.7 Handle all films carefully during the processing cycle and allow adequate time for the film to sufficiently drain before transferring it to the next solution. The use of a stop bath or clear water rinse between developing and fixing may also be appropriate. The stop bath or clear water rinse serves to arrest development and also aids in minimizing the amount of developer carried over into the fixer solution. Insufficient bath-to-bath drain time may cause excessive solution carry-over which can contaminate and shorten the life of solutions in addition to causing undesirable effects on processed radiographs.

7.1.8 When washing films, a wettening agent may be appropriate to use to prevent water spots and streaking during drying.

7.1.9 Caution — Prior to placing films in the dryer, ensure that the dryer is clean and that adequate heat and ventilation are provided. During drying, visually examine the films to determine the length of time required for sufficient drying.

7.2 *Automated Processing:*

7.2.1 Immersion time and solution temperature relationships can be more closely controlled with automatic processing since the equipment provides external gages for monitoring purposes. As a general guideline, follow the manufacturer's recommendations for industrial processing materials. However, the actual procedure used should be based on the variables encountered by the user and his particular needs. Check solution temperatures daily with a thermometer to ensure that the processor's thermometers are accurate [±1°F (0.5°C)].

7.2.2 Check the machine speed by measuring the time it takes for a given length of film to pass a specific point. (For example, if the indicated machine speed is 2 ft/min, place two marks on a length of film 1 ft apart. The second mark should pass a specific location, such as the entrance to the processor, exactly 30 s after the first mark has passed the same point.) An optional method for measuring processor speed is to install a tachometer on the main drive motor and determine desired RPM/processing speed relationships.

7.2.3 Agitation is provided by the action of the processor rollers, recirculation pumps, wash water flow, and no external agitation is needed.

7.2.4 For processors with replenishment systems, use the replenishment rates recommended by the film or solution manufacturer.

7.2.4.1 Accurate replenishment increases the useful life of solutions to a great extent by replacing ingredients that are depleted and maintains the process at a constant, efficient level.

7.2.4.2 Check replenishment systems at least daily to ensure that correct volumes are being injected into the solutions. For installations processing very large amounts of film (in excess of two tank turnovers of replenisher per week), checks on replenishment rates should be made more frequently. Processor manufacturer's recommendations will generally provide an adequate procedure for checking replenishment volumes.

7.2.5 For seasoning freshly mixed developer solution, refer to the provisions in 7.1.5.

7.2.6 Always fill the fixer tank first, following the manufacturer's instructions, then rinse and fill the developer tank. This minimizes the possibility of fixer accidentally splashing into the developer solution. When replacing or removing processor racks, always use a splash guard to further reduce the possibility of contamination.

7.2.7 *Drying:*

7.2.7.1 Make sure the dryer is clean and that no foreign material has settled on the rollers. Routinely examine the ventilation system to ensure that air paths are not blocked and that films are uniformly dried. The heat setting used for air temperature should be compatible with the film manufacturer's recommendations.

7.2.7.2 The dryer efficiency can be tested by processing six consecutive 14 by 17-in. (35 by 43-cm) production films, or equivalent, and examining them immediately after the drying cycle is complete. If damp or undried areas are observed, increase the dryer temperature. Should an increase in temperature not dry the film, retest the fixer activity.

7.3 *Dry Processing:*

7.3.1 Follow manufacturer's recommendations for thermal processor warm-up requirements.

7.3.2 Follow time-temperature recommendations from the manufacturer.

8. Activity Testing of Solutions for Manual and Automatic Processing

8.1 *Developer* — A suggested method of testing developer activity is by processing a production radiography with a known *aim* density in the area of interest, and then measuring the actual density in that area. The actual density should be within ±0.15 log E units of the expected *aim* density.

NOTE 2 — The term *known aim density* refers to an area on a routinely radiographed part (such as a flange or a step wedge) whose thickness or composition is consistent. This area provides a *benchmark* density for the process, and can serve the function normally associated with a process control strip.

8.2 *Fixer:*

8.2.1 Fixer solution activity can be tested by determining the time required to remove the silver from an unexposed film. The film should be periodically agitated during processing. An active fixer solution should remove the silver (the cloudy appearance in the fixer bath should disappear) in approximately one-half of the time recommended for the process.

8.2.2 If physical examination shows unfixed spots or areas, the fixer should be discarded. Unfixed areas may appear as dull, nonreflective areas that may be yellowish in color depending on the actual lack of fixer activity.

8.3 *Wash:*

8.3.1 Proper washing is necessary to remove residual fixer from the film. If not removed from the film, these chemicals will cause subsequent damage (staining) and deterioration of the radiographic image, especially in low density areas.

8.3.2 The effectiveness of washing may be checked using the *residual processing chemicals* test described in Guide E 94 or ANSI PH 4.8.

8.3.3 If physical examination of the films after washing shows dirt or scum that was not present before washing, the wash tanks should be drained and cleaned. Drain wash tanks whenever they are not being used. In order to minimize washing artifacts it is recommended that *scavenger films* be processed at start up to clear out scum and foreign material; the use of algaecides is also recommended to retard the growth of organisms within the wash bath.

9. Records

9.1 Accurate records should be kept of the following items:

9.1.1 Brand name and model of processor, if used.

9.1.2 Brand names and batch number of chemicals used.

9.1.3 Time of development.

9.1.4 Temperature of processing chemicals.

9.1.5 Date new chemicals were placed in use.

9.1.6 Replenishment rates.

10. Maintenance

10.1 Maintenance schedules provided by the manufacturer for preventive maintenance should be adhered to in order to assure consistent chemical and mechanical operation as set forth by the manufacturer.

11. Keywords

11.1 automatic processing; film; manual processing; processing; radiographic; solutions

STANDARD PRACTICE FOR DESIGN, MANUFACTURE, AND MATERIAL GROUPING CLASSIFICATION OF HOLE-TYPE IMAGE QUALITY INDICATORS (IQI) USED FOR RADIOLOGY

SE-1025

(Identical with ASTM Specification E 1025-98)

1. Scope

1.1 This practice covers the design, material grouping classification, and manufacture of hole-type image quality indicators (IQI) used to indicate the quality of radiologic images.

1.2 This practice is applicable to X-ray and gamma-ray radiology.

1.3 The values stated in inch-pound units are to be regarded as standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

B 139 Specification for Phosphor Bronze Rod, Bar, and Shapes
B 150 Specification for Aluminum Bronze Rod, Bar, and Shapes
B 161 Specification for Nickel Seamless Pipe and Tube
B 164 Specification for Nickel-Copper Alloy Rod, Bar, and Wire
B 166 Specification for Nickel-Chromium-Iron Alloys (UNS N06600, N06601, and N06690) and Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617) Rod, Bar, and Wire
E 1316 Terminology for Nondestructive Examinations

3. Terminology

3.1 *Definitions* — The definitions of terms relating to gamma and x-radiology in Terminology E 1316, Section D, shall apply to the terms used in this practice.

4. Hole-Type IQI Requirements

4.1 Image quality indicators (IQIs) used to determine radiologic-image quality levels shall conform to the following requirements.

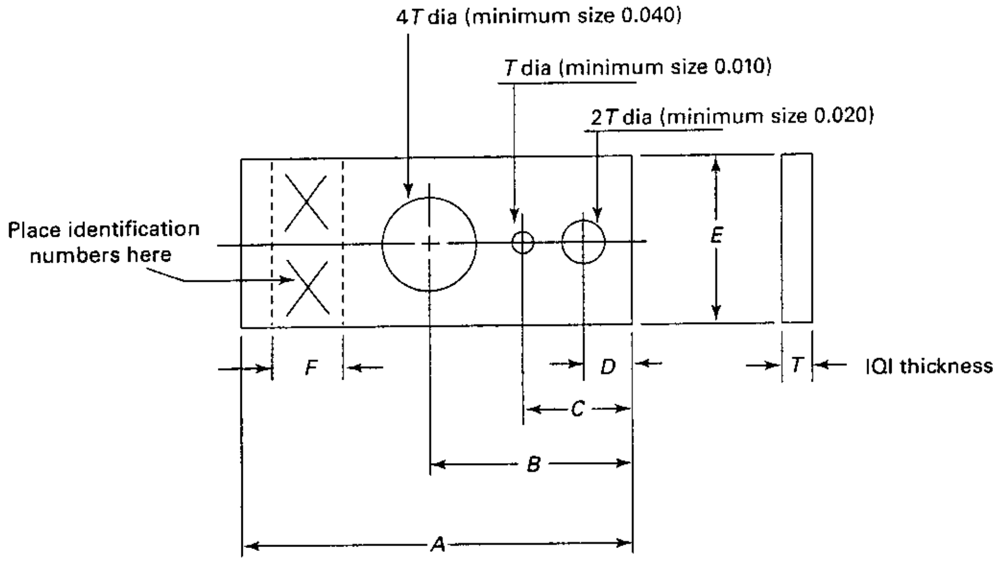
4.1.1 *Standard Hole-Type IQIs:*

4.1.1.1 Image quality indicators (IQIs) shall be fabricated from materials or alloys identified or listed in accordance with 7.3. Other materials may be used in accordance with 7.4.

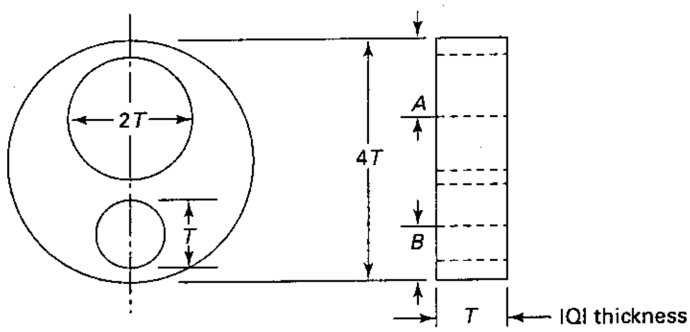
4.1.1.2 Image quality indicators (IQIs) shall dimensionally conform to the requirements of Fig. 1.

4.1.1.3 Both the rectangular and the circular IQI shall be identified with number(s) made of lead or a material of similar radiation opacity. The number shall be bonded to the rectangular IQIs and shall be placed adjacent to circular IQIs to provide identification of the IQI on the image. The identification numbers shall indicate the thickness of the IQI in thousandths of an inch, that is, a number 10 IQI is 0.010 in. thick, a number 100 IQI is 0.100 in. thick, etc. Additional identification requirements are provided in 7.2.

4.1.1.4 Alloy-group identification shall be in accordance with Fig. 2. Rectangular IQIs shall be



(a) Design for IQIs to and Including 160



(b) Design for IQIs Over 160

Note 1 — All dimensions in inches (Note 6).
Note 2 — Tolerances for IQI thickness and hole diameter.
Note 3 — XX identification number equals T in 0.001 inches.
Note 4 — IQIs No. 1 through 9 are not $1T$, $2T$, and $4T$.
Note 5 — Holes shall be true and normal to the IQI. Do not chamfer.
Note 6 — To convert inch dimensions to metric, multiply by 25.4.

Identification Number *T* (Note 3)	*A*	*B*	*C*	*D*	*E*	*F*	Tolerances (Note 2)
1–4	1.500 ± 0.015	0.750 ± 0.015	0.438 ± 0.015	0.250 ± 0.015	0.500 ± 0.015	0.250 ± 0.030	± 10%
5–20	1.500 ± 0.015	0.750 ± 0.015	0.438 ± 0.015	0.250 ± 0.015	0.500 ± 0.015	0.250 ± 0.030	± 0.0005
21–50	. . .	. . .	. . .	. . .	. . .	. . .	± 0.0025
Over 50–160	2.250 ± 0.030	1.375 ± 0.030	0.750 ± 0.030	0.375 ± 0.030	1.000 ± 0.030	0.375 ± 0.030	± 0.005
Over 160	1.330T ± 0.005	0.830T ± 0.005	. . .	. . .	. . .	. . .	± 0.010

FIG. 1 IQI DESIGN

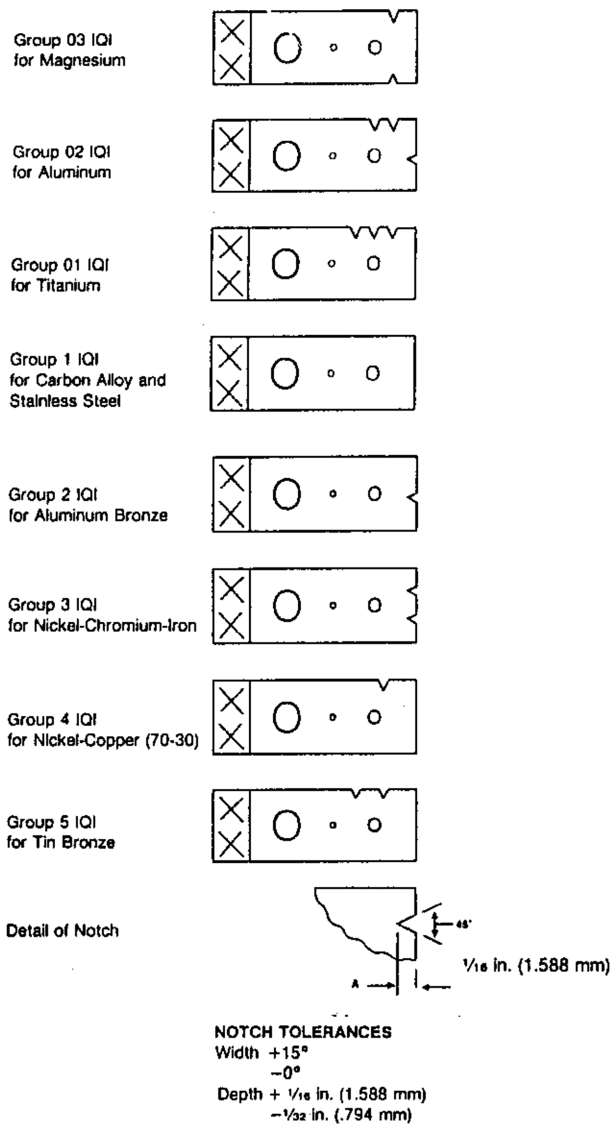


FIG. 2 RECTANGULAR IQI NOTCH IDENTIFICATION AND MATERIAL GROUPING

notched. Image quality indicators (IQIs) shall be vibro-tooled or etched as specified.

4.1.2 *Modified Hole-Type IQI:*

4.1.2.1 The rectangular IQI may be modified in length and width as necessary for special applications, provided the hole size(s) and IQI thickness conform to Fig. 1.

4.1.2.2 The IQIs shall be identified as specified in 4.1.1.3, except that the identification numbers may be placed adjacent to the IQI if placement on the IQI is impractical.

4.1.2.3 When modified IQIs are used, details of the modification shall be documented in the records accompanying the examination results.

5. IQI Procurement

5.1 When selecting IQIs for procurement, the following factors should be considered:

5.1.1 Determine the alloy group(s) of the material to be examined.

5.1.2 Determine the thickness or thickness range of the material(s) to be examined.

5.1.3 Select the applicable IQIs that represent the required IQI thickness and alloy(s).

NOTE 1 — This practice does not recommend or suggest specific IQI sets to be procured. Section 5 is an aid in selecting IQIs based on specific needs.

6. Image Quality Levels

6.1 Image quality levels are designated by a two part expression *X-YT*. The first part of the expression *X* refers to the IQI thickness expressed as a percentage of the specimen thickness. The second part of the expression *YT* refers to the diameter of the hole and is expressed as a multiple of the IQI thickness, *T*. The image quality level 2-2*T* means that the IQI thickness *T* is 2% of the specimen thickness and that the diameter of the IQI imaged hole is 2 × the IQI thickness.

NOTE 2 — Image Quality Indicators (IQIs) less than number 10 have hole sizes 0.010, 0.020, and 0.040 in. diameter regardless of the IQI thickness. Therefore, IQIs less than number 10 do not

TABLE 1
TYPICAL IMAGE QUALITY LEVELS

Image Quality Levels	IQI Thickness	Minimum Perceptible Hole Diameter	Equivalent IQI Sensitivity, %[B]
Standard Image Quality Levels			
2-1 *T*	$\frac{1}{50}$ (2%) of Specimen Thickness	1 *T*	1.4
2-2 *T*[A]		2 *T*	2.0
2-4 *T*		4 *T*	2.8
Special Image Quality Levels			
1-1 *T*	$\frac{1}{100}$ (1%) of Specimen Thickness	1 *T*	0.7
1-2 *T*		2 *T*	1
4-2 *T*	$\frac{1}{25}$ (4%) of Specimen Thickness	2 *T*	4

[A]For *Level 2-2T Radiologic* — The 2 *T* hole in an IQI, $\frac{1}{50}$ (2%) of the specimen thickness, is visible.
[B]Equivalent IQI sensitivity is that thickness of the IQI, expressed as a percentage of the part thickness, in which the 2 *T* hole would be visible under the same conditions.

represent the quality levels specified in 6.1 and Table 1. The equivalent sensitivity can be computed from data furnished in Appendix X1.

6.2 Typical image quality level designations are shown in Table 1. The level of inspection specified should be based on service requirements of the product. Care should be taken in specifying image quality levels 2-1*T*, 1-1*T*, and 1-2*T* by first determining that these levels can be maintained in production.

6.3 In specifying image quality levels, the contract, purchase order, product specification, or drawing should state the proper two-part expression and clearly indicate the thickness of the metal to which the level refers. In place of a designated two-part expression, the IQI number and minimum discernible hole size shall be specified.

7. Material Groups

7.1 *General:*

7.1.1 Materials have been designated in eight groups based on their radiation absorption characteristics: Groups 03, 02, and 01 for light metals and Groups 1 through 5 for heavy metals.

7.1.2 The light metal groups, magnesium (Mg), aluminum (A1), and titanium (Ti), are identified 03, 02, and 01 respectively for their predominant alloying constituent. The materials are listed in order of increasing radiation absorption.

7.1.3 The heavy metal groups, steel, copper base, nickel base, and kindred alloys, are identified 1 through

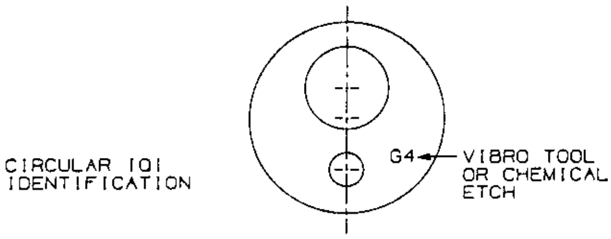


FIG. 3 CIRCULAR IQI IDENTIFICATION

5. The materials increase in radiation absorption with increasing numerical designation.

NOTE 3 — These groups were established experimentally at 180 kV on $\frac{3}{4}$-in. (19-mm) thick specimens. They apply from 125 kV to the multivolt range.

7.1.4 Common trade names or alloy designations have been used for clarification of the pertinent materials.

7.1.5 The materials from which the IQI for the group are to be made are designated in each case, and these IQIs are applicable for all materials listed in that group. In addition, any group IQI may be used for any material with a higher group number, provided the applicable quality level is maintained.

7.2 *Identification System:*

7.2.1 A notching system has been designated for the eight groups of IQIs and is shown in Fig. 2.

7.2.2 For circular IQIs, a group designation shall be vibrotooled or chemically etched on the IQI to identify it by using the letter "G" followed by the group number, that is, G4 for a Group 4 IQI. For identification of the group on the image, corresponding lead characters shall be placed adjacent to the circular IQI, just as is done with the lead numbers identifying the thickness. The identification is shown in Fig. 3.

7.3 *Materials Groups:*

7.3.1 *Materials Group* 03:

7.3.1.1 Image quality indicators (IQIs) shall be made of magnesium or magnesium shall be the predominant alloying constituent.

7.3.1.2 Use on all alloys of which magnesium is the predominant alloying constituent.

7.3.2 *Materials Group* 02:

by the respective repair cycle (that is, R-1 for the first repair, R-2 for the second repair, etc.). Subsequent radiographs that are necessary as a result of additional surface preparation should be identified by the letters "REG."

9.11 *Multiple Film Techniques* — Two or more films of equal or different speeds in the same cassette are allowed, provided prescribed quality level and density requirements are met (see 9.7.2 and 9.7.5).

9.12 *Radiographic Techniques:*

9.12.1 *Single Wall Technique* — Except as provided in 9.12.2, radiography shall be performed using a technique in which the radiation passes through only one wall.

9.12.2 *Double Wall Technique* — For castings with an inside diameter of 4 in. or less, a technique may be used in which the radiation passes through both walls and both walls are viewed for acceptance on the same film. An adequate number of exposures shall be taken to ensure that required coverage has been obtained.

9.13 Safety — Radiographic procedures shall comply with applicable city, state, and federal regulations.

10. Radiograph Evaluation

10.1 Film Quality — Verify that the radiograph meets the quality requirements specified in 8.3, 8.4, 8.6, 9.5.2 and 9.7.

10.2 Film Evaluation — Determine the acceptance or rejection of the casting by comparing the radiographic image to the agreed upon acceptance criteria (see 8.5).

11. Reference Radiographs

11.1 Reference Radiographs E 155, E 186, E 192, E 272, E 280, E 310, E 446, E 505, E 689, and E 802 are graded radiographic illustrations of various casting discontinuities. These reference radiographs may be used to help establish acceptance criteria and may also be useful as radiographic interpretation training aids.

12. Report

12.1 The following radiographic records shall be maintained as agreed upon between purchaser and supplier:

12.1.1 Radiographic standard shooting sketch,

12.1.2 Weld repair documentation,

12.1.3 Film,

12.1.4 Film interpretation record containing as a minimum:

12.1.4.1 Disposition of each radiograph (acceptable or rejectable),

12.1.4.2 If rejectable, cause for rejection (shrink, gas, etc.),

12.1.4.3 Surface indication verified by visual examination (mold, marks, etc.), and

12.1.4.4 Signature of the film interpreter.

13. Precision and Bias

13.1 No statement has been made about either the precision or bias of this test method since the result merely states whether there is conformance to the criteria for success specified in the procedure.

14. Keywords

14.1 castings; gamma-ray; nondestructive testing; radiographic; radiography; x-ray

and dimensional tolerances of the IQIs specified by this practice.

9. Precision and Bias

9.1 *Precision and Bias* — No statement is made about the precision or bias for indicating the quality of radiographs since the results merely state whether there is conformance to the criteria for success specified in this practice.

10. Keywords

10.1 density; image quality level; IQI; radiologic; radiology; X-ray and gamma radiation

APPENDIX

(Nonmandatory Information)

X1. EQUIVALENT IQI (PENETRAMETER) SENSITIVITY (EPS)

X1.1 To find the equivalent IQI sensitivity (percent), the hole size (diameter in inches), of the IQI thickness (inches), for a section thickness (inches), the following computations may be used:

$$\alpha = \frac{100}{X}\sqrt{\frac{TH}{2}},$$

where:

α = equivalent IQI sensitivity, %,
X = section thickness to be examined, in.,
T = IQI thickness, in., and
H = hole diameter, in.

X1.2 Alternate method for determining EPS using Fig. X1.1 Nomograph:

Example:

Given:

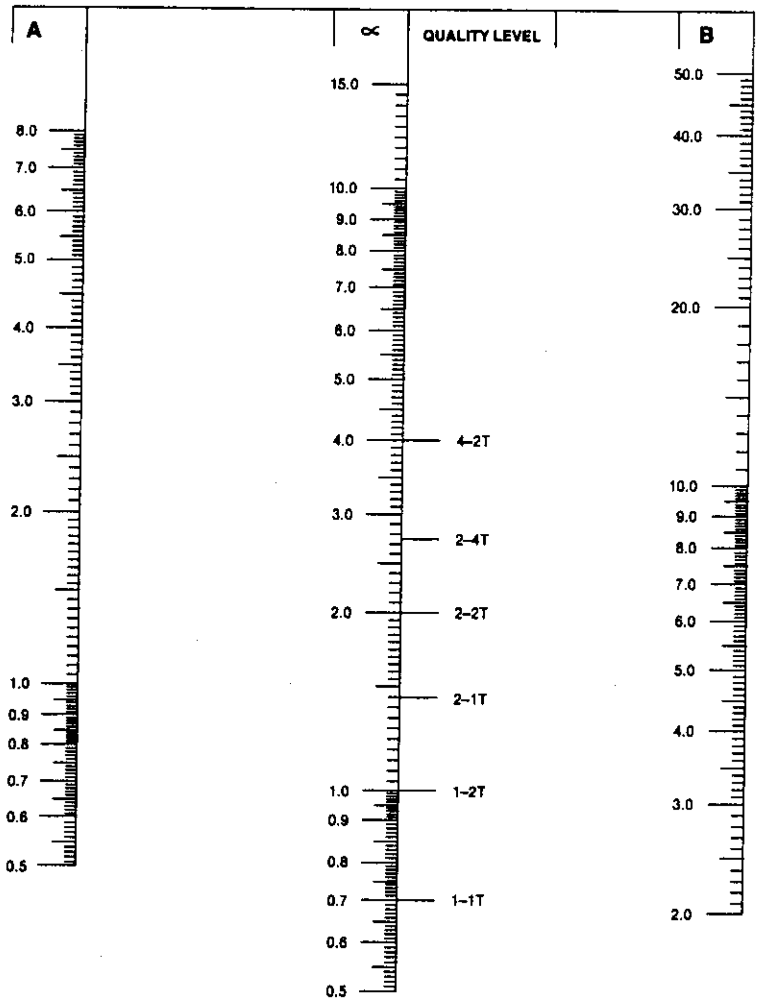
X=0.5 in.
T=0.005 in., and
H=0.0625 in.

Solution:

$$A = \frac{100T}{X} = \frac{100 \times 0.005}{0.5} = 1.0\%$$

$$B = \frac{100H}{X} = \frac{100 \times 0.0625}{0.5} = 12.5\%$$

X1.3 Proceed to the nomograph (Fig. X1.1) and draw a line joining the 1.0% Value A and the 12.5% Value B and look on the center percent scale where the line crosses it and read the answer — 2.5%. Thus under the given conditions, equivalent IQI (penetrameter) sensitivity (EPS) is 2.5%.



Definitions:

A equals the visible IQI (penetrameter) plaque thickness (*T*) expressed as a percentage of the section (object) thickness to be radiographed in (inches).

B equals the diameter of the smallest IQI (penetrameter) hole (*H*) for which the image is visibly expressed as a percentage of the section (object) thickness to be radiographed in (inches).

Note — The nomograph is used for computing equivalent IQI sensitivity from *T* (*T* equals penetrameter thickness) inches and *H* (*H* equals hole diameter) inches. Draw a straight line joining the values on any two scales, and look on the third scale where the line crosses and read the answer. Due to normal reproduction methods in producing the nomograph, some small error (that is, less than 5%) may occur. If more accurate results are required, the formula in Appendix X1 should be used.

FIG. X1.1 EQUIVALENT IQI (PENETRAMETER) SENSITIVITY NOMOGRAPH

STANDARD TEST METHOD FOR RADIOGRAPHIC EXAMINATION OF METALLIC CASTINGS

SE-1030

(Identical with ASTM Specification E 1030-95)

1. Scope

1.1 This test method provides a uniform procedure for radiographic examination of metallic castings using radiographic film as the recording medium.

1.2 Due to the many complex geometries and part configurations inherent with cast products, it is necessary to recognize potential limitations associated with obtaining complete radiographic coverage on castings. Radiography of areas where geometry or part configuration does not allow achievement of complete coverage with practical radiographic methods shall be subject to mutual agreements between purchaser and supplier. The use of alternative nondestructive methods for areas that are not conducive to practical radiography shall also be specifically agreed upon between purchaser and supplier.

1.3 The radiographic method is highly sensitive to volumetric discontinuities that displace a detectable volume of cast material. Discontinuities that do not displace an appreciable volume of material, however, such as cracks or other planar-type indications, may not be detected with radiography unless the radiation beam is coincidentally aligned with the planar orientation of the discontinuity. In view of this limitation, it may be considered appropriate to use the radiographic method in conjunction with additional nondestructive methods that maintain reliable detection capabilities for these types of discontinuities. The use of additional methods shall be specifically agreed upon between the purchaser and supplier.

1.4 The values stated in inch-pound units are to be regarded as standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 94 Guide for Radiographic Testing
E 142 Method for Controlling Quality of Radiographic Testing
E 155 Reference Radiographs for Inspection of Aluminum and Magnesium Castings
E 186 Reference Radiographs for Heavy-Walled [2 to $4\frac{1}{2}$-in. (51 to 114-mm)] Steel Castings
E 192 Reference Radiographs of Investment Steel Castings for Aerospace Applications
E 272 Reference Radiographs for High-Strength Copper-Base and Nickel-Copper Alloy Castings
E 280 Reference Radiographs for Heavy-Walled [$4\frac{1}{2}$ to 12-in. (114 to 305-mm)] Steel Castings
E 310 Reference Radiographs for Tin Bronze Castings
E 446 Reference Radiographs for Steel Castings Up to 2 in. (51 mm) in Thickness
E 505 Reference Radiographs for Inspection of Aluminum and Magnesium Die Castings
E 543 Practice for Evaluating Agencies that Perform Nondestructive Testing
E 689 Reference Radiographs for Ductile Iron Castings
E 746 Test Method for Determining Relative Image Quality Response of Industrial Radiographic Film
E 747 Practice for the Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used For Radiology
E 802 Reference Radiographs for Gray Iron Castings Up to $4\frac{1}{2}$ in. (114 mm) in Thickness

E 999 Guide for Controlling the Quality of Industrial Radiographic Film Processing
E 1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology
E 1254 Guide for Storage of Radiographs and Unexposed Industrial Radiographic Film
E 1316 Terminology for Nondestructive Examination

2.2 *ASNT/ANSI Standards:*
Recommended Practice No. SNT-TC-1A "Personnel Qualification and Certification in Nondestructive Testing"
CP-189 Qualification and Certification of Nondestructive Testing Personnel

2.3 *Military Standard:*
MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification

3. Terminology

3.1 *Definitions* — For definitions of terms used in this test method, see Terminology E 1316.

4. Significance and Use

4.1 The requirements expressed in this test method are intended to control the quality of the radiographic images, to produce satisfactory and consistent results, and are not intended for controlling the acceptability or quality of materials or products.

5. Basis of Application

5.1 The following items shall be agreed upon by the purchaser and supplier:

5.1.1 *Nondestructive Testing Agency Evaluation* — If specified in the contractual agreement, nondestructive testing (NDT) agencies shall be qualified and evaluated in accordance with Practice E 543. The applicable version of Practice E 543 shall be specified in the contractual agreement.

5.1.2 *Personnel Qualification* — NDT personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, MIL-STD-410 or a similar document. The practice or standard used and its applicable revision shall be specified in the contractual agreement between the using parties.

5.1.3 *Requirements* — General requirements (see 8.1, 8.2, 8.5, and 8.7.4) shall be specified.

5.1.4 Procedure Requirements (see 9.1, 9.1.1, 9.3, and 9.7.7) shall be specified.

5.1.5 *Records* — Record retention (see 12.1) shall be specified.

6. Apparatus

6.1 *Radiation Sources:*

6.1.1 *X Radiation Sources* — Selection of appropriate X-ray voltage and current levels is dependent upon variables regarding the specimen being examined (material type and thickness) and economically permissible exposure time. The suitability of these X-ray parameters shall be demonstrated by attainment of required penetrameter (IQI) sensitivity and compliance with all other requirements stipulated herein. Guide E 94 contains provisions concerning exposure calculations and charts for the use of X-ray sources.

6.1.2 *Gamma Radiation Sources* — Isotope sources, when used, shall be capable of demonstrating the required radiographic sensitivity.

6.2 *Film Holders and Cassettes* — Film holders and cassettes shall be light-tight and shall be handled properly to reduce the likelihood that they may be damaged. They may be flexible vinyl, plastic, or any durable material; or, they may be made from metallic materials. In the event that light leaks into the film holder and produces images on the film extending into the area of interest, the film shall be rejected. If the film holder exhibits light leaks, it shall be repaired before reuse or discarded. Film holders and cassettes should be routinely examined to minimize the likelihood of light leaks.

6.3 *Intensifying Screens:*

6.3.1 *Lead-Foil Screens:*

6.3.1.1 Intensifying screens of the lead-foil type are generally used for all production radiography. Lead-foil screens shall be of the same approximate area dimensions as the film being used and they shall be in direct contact with the film during exposure.

6.3.1.2 For X-ray voltages between 200 kV and 1 MeV, front and rear screen thicknesses shall be a minimum of 0.005 in. (0.13 mm) thick. Below 200 kV, front screen thicknesses up to 0.005 in. (0.13 mm) and rear screen thicknesses of at least 0.005 in. (0.13 mm) should be used if they improve radiographic quality. For isotope and high-voltage X-radiography (greater than 1 MeV) increased thicknesses may be

appropriate for improvements in radiographic quality and should be used accordingly. Intermediate screens (between multiloaded film) may be used if desired.

6.3.1.3 Sheet lead, with or without backing, used for screens should be visually examined for dust, dirt, oxidation, cracking or creasing, foreign material or other conditions that could render undesirable nonrelevant images on the film.

6.3.1 *Fluorescent or Fluorometallic Screens:*

6.3.2.1 Fluorescent or fluorometallic screen may be used. However, they must be capable of demonstrating the required penetrameter (IQI) sensitivity.

6.3.2.2 *Screen Care* — All screens should be handled carefully to avoid dents, scratches, grease, or dirt on active surfaces. Screens that render false indications on radiographs shall be discarded or reworked to eliminate the artifact.

6.4 *Filters* — Filters shall be used whenever the contrast reductions caused by low-energy scattered radiation or the extent of undercut and edge burn-off occurring on production radiographs is of significant magnitude so as to cause failure to meet the quality level or radiographic coverage requirements stipulated by the job order or contract (see Guide E 94).

6.5 *Masking* — Masking material may be used, as necessary, to help reduce image degradation due to undercutting (see Guide E 94).

6.6 *Penetrameters (IQI)* — Unless otherwise specified by the applicable job order or contract, only those penetrameters that comply with the design and identification requirements specified in Practice E 747 or Practice E 1025 shall be used.

6.7 *Shims and Separate Blocks* — Shims or separate blocks made of the same or radiographically similar materials (as defined in Method E 142) may be used to facilitate penetrameter positioning. There is no restriction on shim or separate block thickness provided the penetrameter and area-of-interest density tolerance requirements of 9.7.6.2 are met.

6.8 *Radiographic Location and Identification Markers* — Lead numbers and letters are used to designate the part number and location number. The size and thickness of the markers shall depend on the ability of the radiographic technique to image the markers on the radiograph. As a general rule, markers $^1/_{16}$ in. (1.58 mm) thick will suffice for most low energy (less than 1 MeV) X-ray and Iridium-192 radiography; for higher energy radiography it may be necessary to use markers that are $^1/_8$ in. (3.17 mm) or more thick.

6.9 *Radiographic Density Measurement Apparatus* — Either a transmission densitometer or a step-wedge comparison film shall be used for judging film density requirements. Step wedge comparison films or densitometer calibration, or both, shall be verified by comparison with a calibrated step-wedge film traceable to the National Institute of Standards and Technology.

7. Reagents and Materials

7.1 *Films* — Definite rules on selection of films cannot be given since choice depends on such factors as the required radiographic quality level and the maximum economically permissible exposure time. In any case, the films selected must be capable of demonstrating the required penetrameter (IQI) sensitivity.

NOTE — Test Method E 746 provides a method for determining the relative image quality response of industrial radiographic film and may be used as the basis for film selection.

8. Requirements

8.1 *Procedure Requirement* — Unless otherwise specified by the applicable job order or contract, radiographic examination shall be performed in accordance with a written procedure. Specific requirements regarding the preparation and approval of written procedures shall be dictated by a purchaser and supplier agreement. The procedure details should include at least those items stipulated in Appendix X1. In addition, a radiographic standard shooting sketch (RSS), Fig. X1.1, shall be prepared similar to that shown in Appendix X1 and shall be available for review during interpretation of the film.

8.2 *Radiographic Coverage* — Unless otherwise specified by a purchaser and supplier agreement, the extent of radiographic coverage shall be the maximum practical volume of the casting. Areas that require radiography shall be designated as illustrated in Fig. X1.2(*a*) and (*b*) of Appendix X1. When the shape or configuration of the casting is such that radiography is impractical, these areas shall be so designated on drawings or sketches that accompany the radiographs. Examples of casting geometries and configurations that may be considered impractical to radiograph are illustrated in Appendix X2.

8.3 *Radiographic Film Quality* — All radiographs shall be free of mechanical, chemical, handling-related, or other blemishes which could mask or be confused

with the image of any discontinuity in the area of interest on the radiograph. If any doubt exists as to the true nature of an indication exhibited by the film, the radiograph shall be retaken or rejected.

8.4 *Radiographic Quality Level* — The applicable job order or contract shall dictate the requirements for radiographic quality level. (See Practice E 1025 or Practice E 747 for guidance in selection of quality level.)

8.5 *Acceptance Level* — Radiographic acceptance levels and associated severity levels shall be stipulated by the applicable contract, job order, drawing, or other purchaser and supplier agreement.

8.6 *Radiographic Density Limitations* — Radiographic density in the area of interest shall be within 1.5 to 4.0 for either single or superimposed viewing.

8.7 *Film Handling:*

8.7.1 *Darkroom Facilities* — Darkroom facilities should be kept clean and as dust-free as practical. Safelights should be those recommended by film manufacturers for the radiographic materials used and should be positioned in accordance with the manufacturer's recommendations. All darkroom equipment and materials should be capable of producing radiographs that are suitable for interpretation.

8.7.2 *Film Processing* — Radiographic film processing shall be controlled in accordance with Guide E 999.

8.7.3 *Film Viewing Facilities* — Viewing facilities shall provide subdued background lighting of an intensity that will not cause troublesome reflections, shadows, or glare on the radiograph. The viewing light shall be of sufficient intensity to review densities up to 4.0 and be appropriately controlled so that the optimum intensity for single or superimposed viewing of radiographs may be selected.

8.7.4 *Storage of Radiographs* — When storage is required by the applicable job order or contract, the radiographs should be stored in an area with sufficient environmental control to preclude image deterioration or other damage. The radiograph storage duration and location after casting delivery shall be as agreed upon between purchaser and supplier. (See Guide E 1254 for storage information.)

9. Procedure

9.1 *Time of Examination* — Unless otherwise specified by the applicable job order or contract, radiography may be performed prior to heat treatment and in the as-cast, rough-machined, or finished-machined condition.

9.1.1 *Penetrameter (IQI) Selection* — Unless otherwise specified in the applicable job order or contract, penetrameter (IQI) selection shall be based on the following: if the thickness to be radiographed exceeds the design thickness of the finished piece, the penetrameter (IQI) size shall be based on a thickness which does not exceed the design thickness of the finished piece by more than 20% or 1/4 in. (6.35 mm), whichever is greater. In no case shall the penetrameter (IQI) size be based on a thickness greater than the thickness to be radiographed.

9.2 *Surface Preparation* — The casting surfaces shall be prepared as necessary to remove any conditions that could mask or be confused with internal casting discontinuities.

9.3 *Source-to-Film Distance* — Unless otherwise specified in the applicable job order or contract, geometric unsharpness (Ug) shall not be greater than one percent of the maximum part thickness being interpreted on the radiograph, or 0.070 in. (1.8 mm), whichever is less. Geometric unsharpness values shall be determined as specified in Guide E 94.

9.4 *Direction of Radiation* — The direction of radiation shall be governed by the geometry of the casting and the radiographic coverage and quality requirements stipulated by the applicable job order or contract. Whenever practicable, place the central beam of the radiation perpendicular to the surface of the film. Appendix X2 provides examples of preferred source and film orientations and examples of casting geometries and configurations on which radiography is impractical or very difficult.

9.5 *Back-Scattered Radiation Protection:*

9.5.1 *Back-Scattered Radiation* — (secondary radiation emanating from surfaces behind the film, that is, walls, floors, etc.) serves to reduce radiographic contrast and may produce undesirable effects on radiographic quality. A 1/8-in. (3.17 mm) lead sheet placed behind the film generally furnishes adequate protection against back-scattered radiation.

9.5.2 To detect back-scattered radiation, position a lead letter "B" [approximately 1/8 in. (3.17 mm) thick by 1/2 in. (12.7 mm) high] on the rear side of the film holder. If a light image (lower density) of the lead letter "B" appears on the radiograph, it indicates that more back-scatter protection is necessary. The appearance of a dark image of the lead letter "B" should be

disregarded unless the dark image could mask or be confused with rejectable casting defects.

9.6 *Penetrameter (IQI) Placement* — Place all penetrameters (IQI) being radiographed on the source side of the casting. Place penetrameters (IQIs) in the radiographic area of interest, unless the use of a shim or separate block is necessary, as specified in 9.7.6.

9.7 *Number of Penetrameters (IQIs):*

9.7.1 One penetrameter (IQI) shall represent an area within which radiographic densities do not vary more than +30% to −15% from the density measured through the body of the penetrameter (IQI).

9.7.2 When the film density varies more than −15% to +30%, two penetrameters (IQIs) used as follows will be acceptable: if one penetrameter (IQI) shows acceptable sensitivity representing the most dense portion of the exposure, and the second penetrameter (IQI) shows acceptable sensitivity representing the least dense portion of the exposure, then these two penetrameters (IQIs) shall qualify the exposure location within these densities, provided the density requirements stipulated in 8.6 are met.

9.7.3 For cylindrical or flat castings where more than one film holder is used for an exposure, at least one penetrameter (IQI) image shall appear on each radiograph. For cylindrical shapes, where a panoramic type source of radiation is placed in the center of the cylinder and a complete or partial circumference is radiographed using at least four overlapped film holders, at least three penetrameters (IQIs) shall be used. On partial circumference exposures, a penetrameter (IQI) shall be placed at each end of the length of the image to be evaluated on the radiograph with the intermediate penetrameters (IQIs) placed at equal divisions of the length covered. For full circumferential coverage, three penetrameters (IQIs) spaced 120° apart shall be used, even when using a single length of roll film.

9.7.4 When an array of individual castings in a circle is radiographed, the requirements of 9.7.1 or 9.7.2, or both, shall prevail for each casting.

9.7.5 If the required penetrameter (IQI) sensitivity does not show on any one film in a multiple film technique (see 9.11), but does show in composite (superimposed) film viewing, interpretation shall be permitted only by composite film viewing for the respective area.

9.7.6 When it is not practicable to place the penetrameter(s) (IQI) on the casting, a shim or separate block conforming to the requirements of 6.7 may be used.

9.7.6.1 The penetrameter (IQI) shall be no closer to the film than the source side of that part of the casting being radiographed in the current view.

9.7.6.2 The radiographic density measured adjacent to the penetrameter (IQI) through the body of the shim or separate block shall not exceed the density measured in the area of interest by more than 15%. The density may be lighter than the area of interest density, provided acceptable quality level is obtained and the density requirements of 8.6 are met.

9.7.6.3 The shim or separate block shall be placed at the corner of the film holder or close to that part of the area of interest that is furthest from the central beam. This is the worst case position from a beam angle standpoint that a discontinuity would be in.

9.7.6.4 The shim or separate block dimensions shall exceed the penetrameter (IQI) dimensions such that the outline of at least three sides of the penetrameter (IQI) image shall be visible on the radiograph.

9.7.7 *Film Side Penetrameter (IQI)* — In the case where the penetrameter (IQI) cannot be physically placed on the source side and the use of a separate block technique is not practical, penetrameters (IQIs) placed on the film side may be used. The applicable job order or contract shall dictate the requirements for film side radiographic quality level (see 8.4).

9.8 *Location Markers* — The radiographic image of the location markers for the coordination of the casting with the film shall appear on the film, without interfering with the interpretation, in such an arrangement that it is evident that the required coverage was obtained. These marker positions shall be marked on the casting and the position of the markers shall be maintained on the part during the complete radiographic cycle. The RSS shall show all marker locations.

9.9 *Radiographic Identification* — A system of positive identification of the film shall be provided. As a minimum, the following shall appear on the radiograph: the name or symbol of the inspecting laboratory, the date, the casting identification number, and whether it is an original or subsequent exposure.

9.10 *Subsequent Exposure Identification* — All repair radiographs after the original (initial) shall have an inspection status designation that indicates the reason. Subsequent radiographs made by reason of a repaired area shall be identified with the letter "R" followed

by the respective repair cycle (that is, R-1 for the first repair, R-2 for the second repair, etc.). Subsequent radiographs that are necessary as a result of additional surface preparation should be identified by the letters "REG."

9.11 *Multiple Film Techniques* — Two or more films of equal or different speeds in the same cassette are allowed, provided prescribed quality level and density requirements are met (see 9.7.2 and 9.7.5).

9.12 *Radiographic Techniques:*

9.12.1 *Single Wall Technique* — Except as provided in 9.12.2, radiography shall be performed using a technique in which the radiation passes through only one wall.

9.12.2 *Double Wall Technique* — For castings with an inside diameter of 4 in. or less, a technique may be used in which the radiation passes through both walls and both walls are viewed for acceptance on the same film. An adequate number of exposures shall be taken to ensure that required coverage has been obtained.

9.13 Safety — Radiographic procedures shall comply with applicable city, state, and federal regulations.

10. Radiograph Evaluation

10.1 Film Quality — Verify that the radiograph meets the quality requirements specified in 8.3, 8.4, 8.6, 9.5.2 and 9.7.

10.2 Film Evaluation — Determine the acceptance or rejection of the casting by comparing the radiographic image to the agreed upon acceptance criteria (see 8.5).

11. Reference Radiographs

11.1 Reference Radiographs E 155, E 186, E 192, E 272, E 280, E 310, E 446, E 505, E 689, and E 802 are graded radiographic illustrations of various casting discontinuities. These reference radiographs may be used to help establish acceptance criteria and may also be useful as radiographic interpretation training aids.

12. Report

12.1 The following radiographic records shall be maintained as agreed upon between purchaser and supplier:

12.1.1 Radiographic standard shooting sketch,

12.1.2 Weld repair documentation,

12.1.3 Film,

12.1.4 Film interpretation record containing as a minimum:

12.1.4.1 Disposition of each radiograph (acceptable or rejectable),

12.1.4.2 If rejectable, cause for rejection (shrink, gas, etc.),

12.1.4.3 Surface indication verified by visual examination (mold, marks, etc.), and

12.1.4.4 Signature of the film interpreter.

13. Precision and Bias

13.1 No statement has been made about either the precision or bias of this test method since the result merely states whether there is conformance to the criteria for success specified in the procedure.

14. Keywords

14.1 castings; gamma-ray; nondestructive testing; radiographic; radiography; x-ray

APPENDICES
(Nonmandatory Information)

X1. RADIOGRAPHIC STANDARD SHOOTING SKETCH (RSS)

X1.1 The radiographic standard shooting sketch (RSS) provides the radiographic operator and the radiographic interpreter with pertinent information regarding the examination of a casting. The RSS is designed to standardize radiographic methodologies associated with casting inspection; it may also provide a means of a purchaser and supplier agreement, prior to initiation of the inspection on a production basis. The use of a RSS is advantageous due to the many configurations associated with castings and the corresponding variations in techniques for inspection of any particular one. The RSS provides a map of location marker placement, directions for source and film arrangement, and instructions for all other parameters associated with radiography of a casting. This information serves to provide the most efficient method for controlling the quality and consistency of the resultant radiographic representations.

X1.2 The RSS usually consists of an instruction sheet and sketch(es) of the casting: the instruction sheet specifies the radiographic equipment, materials, and technique-acceptance parameters for each location; the

GENERAL INFORMATION	CASTING IDENTIFICATION		
COMPANY PREPARING RSS	DRAWING NO.	REVISION	PIECE NO.
COMPANY PERFORMING RT	DESCRIPTION BODY		
FOUNDRY CASTING IDENTIFICATION METHOD STAMPED ☒ ETCHED ☐ AT RT LOCATION 9-10	MATERIAL NI-CU	MATERIAL SPEC.	
SURFACE CONDITION WHEN RT'D AS CAST ☐ ROUGH MACH'D ☒ FINISH MACH'D ☐	PATTERN NO.	HEAT NO.	

RSS APPROVAL			
SUPPLIER		CUSTOMER	
1.	DATE	1.	DATE
2.	DATE	2.	DATE

SAMPLE

RT PARAMETERS								
VIEWS	1-2 thru 4-1	5-6 thru 7-8	9-10	11-12	13			
SOURCE TYPE	IRID 192 →							
FINISHED THICKNESS	13/16"	3/4"	5/8"-2-1/8	5/8"-2 3/8	3/4"-2-3/8			
THICKNESS WHEN RT'D	15/16"	7/8"	3/4"-2-5/16	3/4"-2-1/2	7/8"-2-1/2			
PENETRAMETER(S)	17	17	15 - 45	15 - 50	17 - 50			
SOURCE TO FILM DISTANCE	30" →							
FILM TYPE	1 →		1 & 2 →					
FILM SIZE	5 X 7 →		8 X 10 →					
QUALITY LEVEL	2-2T →							
ACCEPTANCE STANDARD	ASTM E-272 →							
SEVERITY LEVEL	2 →							

NOTES	REVISIONS					
	REV.	DESCRIPTION	APPROVAL SUPPLIER BY	DATE	CUSTOMER BY	DATE
	A	ORIGINAL ISSUE	—	—	—	—

RSS NO. XXX-YYY-22	REVISION A	PAGE 1 OF 3

FIG. X1.1 Sample Radiographic Standard Shooting Sketch (RSS)

FIG. X1.1 SAMPLE RADIOGRAPHIC STANDARD SHOOTING SKETCH (RSS)

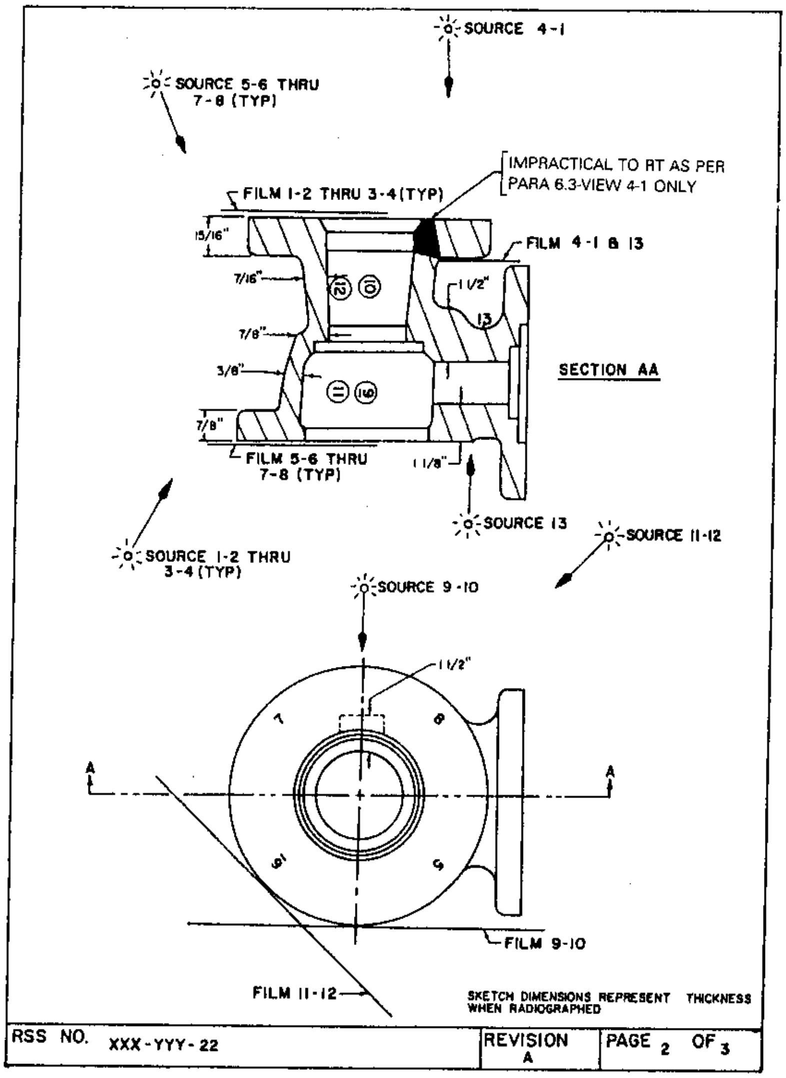


FIG. X1.2 SAMPLES OF RADIOGRAPHIC STANDARD SHOOTING SKETCHES (RSS)
(a) VIEWS ILLUSTRATING LAYOUT AND SOURCE AND FILM PLACEMENT

sketch(es) illustrate(s) the location, orientation, and the source and film arrangement for each location. Figures X1.1 and X1.2(*a*) and (*b*) of this appendix provide a typical instruction sheet and sketch sheets. As a minimum, the RSS should provide the following information. All spaces shall be filled in unless not applicable; in those cases, the space shall be marked NA.

X1.2.1 The instruction sheet should provide the following:

X1.2.1.1 Company preparing RSS and activity performing radiography.

X1.2.1.2 Casting identification including:

(a) Drawing number,

(b) Casting identification number,

(c) Descriptive name (for example, pump casting, valve body, etc.),

(d) Material type and material specification,

(e) Heat number, and

(f) Pattern number.

X1.2.1.3 Surface condition at time of radiography (as cast, rough machined, finished machined).

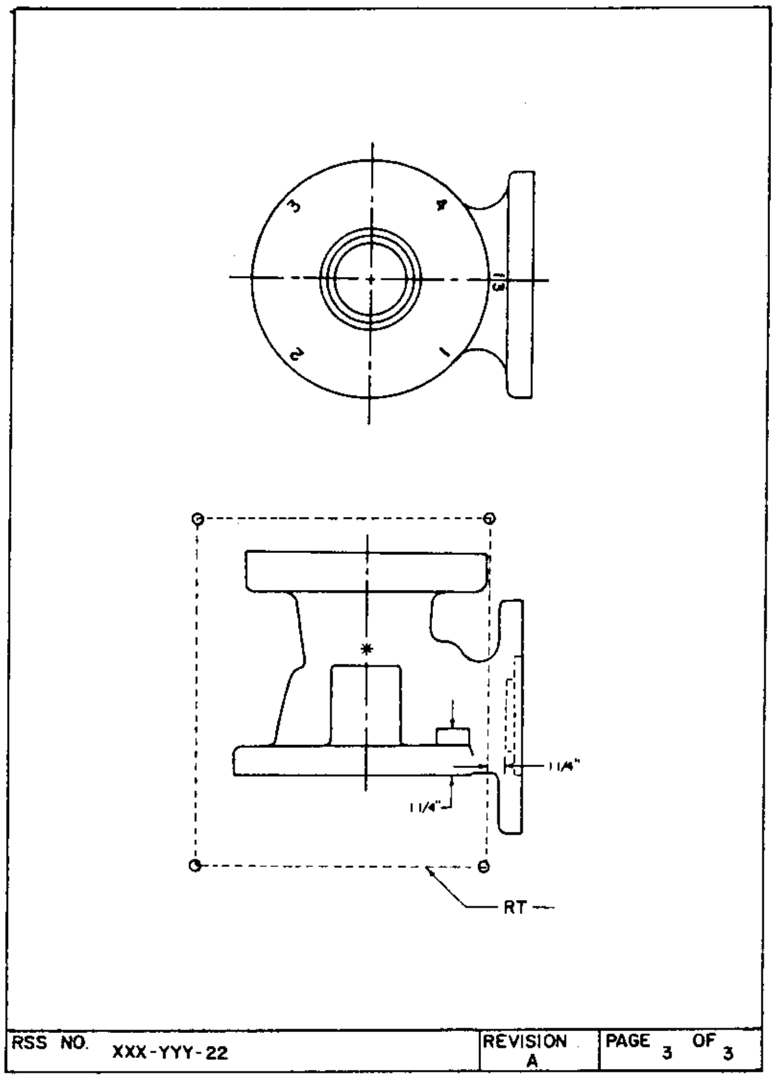


FIG. X1.2(b)
(b) VIEWS ILLUSTRATING LAYOUT AND EXTENT OF COVERAGE

X1.2.1.4 Spaces for approval (as applicable).

X1.2.1.5 *Radiographic Technique Parameters for Each Location:*

(a) Radiographic location designation,
(b) Source type and size,
(c) Finished thickness,
(d) Thickness when radiographed,
(e) Penetrameters,
(f) Source to film distance,
(g) Film type and quantity,
(h) Film size,
(i) Required penetrameter (IQI) quality level,
(j) Radiographic acceptance standard, and
(k) Applicable radiographic severity level.

X1.2.2 The sketch(es) should provide the following:

X1.2.2.1 Location marker placement.

X1.2.2.2 Location of foundry's identification pad or symbol on the casting.

X1.2.2.3 Designation of areas that require radiography (as applicable).

X1.2.2.4 Designation of areas that are considered impractical or very difficult to radiograph (see 1.2 and 8.2).

X1.2.2.5 Radiographic source and film arrangement and radiation beam direction for each location.

NOTE X1.1 — The RSS should designate the involved locations and stipulate that the technique for those locations is typical, for sections of the casting on which a continuing series of locations are to be radiographed with the same basic source and film arrangement for each location.

X1.2.3 Figure X1.1 of this appendix provides a sample RSS that has been developed for a typical production application, and Fig. X1.2(*a*) and (*b*) provide sample RSS sketches that have been developed for a typical production application.

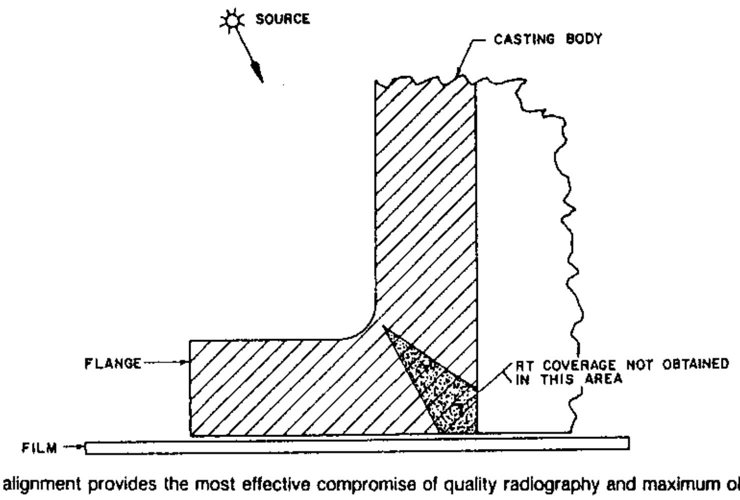
X1.2.4 The RSS may not provide what is considered to be the most effective means of technique control for all radiographic activities, but, in any event, some means of technique standardization should be employed. As a general rule, it is a beneficial practice for the supplier to solicit purchaser approval of the radiographic methodology prior to performing production radiography. This generally entails the demonstration of the adequacy of the methodology by submitting the proposed technique parameters and a corresponding set of pilot radiographs to the purchaser for review. Purchaser approval of the technique shall be addressed in the applicable job order or contract.

X2. PREFERRED SOURCE AND FILM ALIGNMENT FOR FLANGE RADIOGRAPHY AND EXAMPLES OF AREAS THAT ARE CONSIDERED IMPRACTICAL TO RADIOGRAPH

X2.1 Preferred Source and Film Alignment for Flange Radiography — The effective use of radiography for assessing material soundness in casting areas where a flange joins a body is somewhat limited by the source and film alignment that the geometric configuration of these areas requires. The following figures describe source and film alignments that can be employed and discusses the limits and benefits of each.

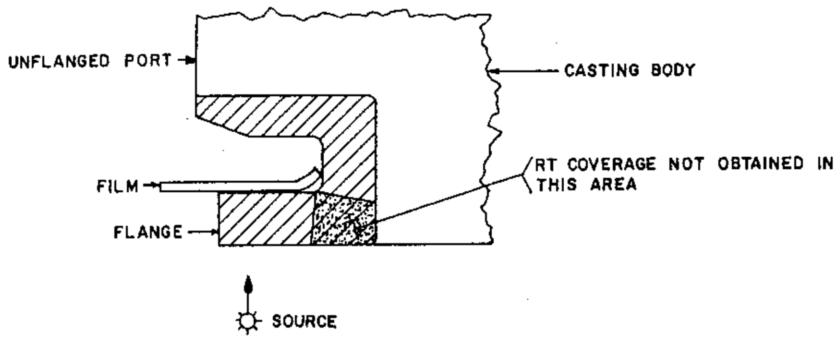
X3. EXAMPLES OF AREAS THAT ARE CONSIDERED TO BE IMPRACTICAL TO RADIOGRAPH

X3.1 Certain casting geometry configuration are inaccessible for conventional source and film arrangements that will provide meaningful radiographic results. These areas generally involve the juncture of two casting sections. The following illustrations provide typical examples of such areas.



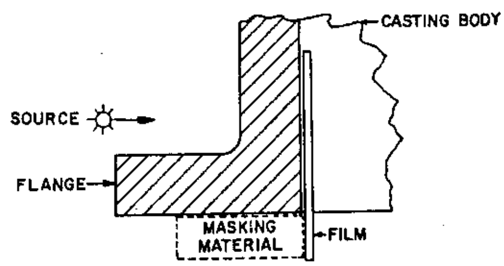
NOTE—For general application, this alignment provides the most effective compromise of quality radiography and maximum obtainable coverage.

FIG. X2.1 PREFERRED SOURCE AND FILM ALIGNMENT



NOTE—This alignment provides a suitable alternative when other casting appendages (bosses, flanges, etc.) project into the radiation path as illustrated in Fig. X2.2 when this alignment is used, additional losses in coverage (as opposed to Fig. X2.1) should be expected and noted accordingly on the applicable RSS.

FIG. X2.2 PERMISSIBLE SOURCE AND FILM ALIGNMENT WHEN FIG. X2.1 CANNOT BE APPLIED DUE TO CASTING GEOMETRY



NOTE—This alignment is permissible if the radiation source energy and film multi-load capabilities are sufficient to afford compliance with the technique requirements stipulated herein. This alignment will generally require the use of filters or masking to reduce the influence of radiation that undercuts the thicker areas and reduces overall radiographic quality.

FIG. X2.3 ALLOWABLE SOURCE FILM ALIGNMENT AS GOVERNED BY SOURCE ENERGY AND MULTI-FILM LOAD ACCEPTANCE DENSITY LATITUDE

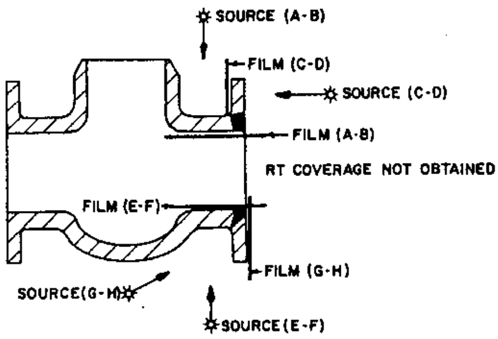


FIG. X3.1 AREAS INVOLVING FLANGES

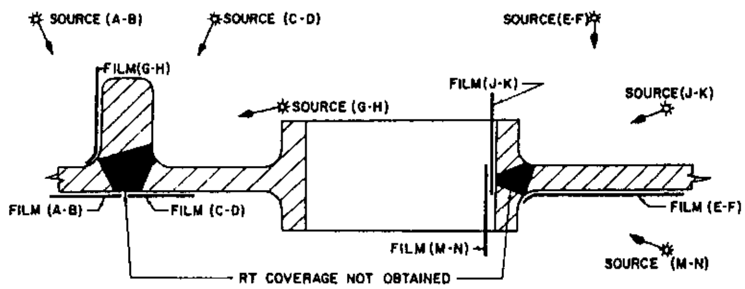


FIG. X3.2 AREAS INVOLVING OTHER JUNCTURES

STANDARD PRACTICE FOR CALIBRATION OF TRANSMISSION DENSITOMETERS

SE-1079

(Identical with ASTM Specification E 1079-97)

1. Scope

1.1 This practice covers the calibration of transmission densitometers used to perform radiographic film density measurements (see Note).

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE — For further information on the design and use of densitometers, the following literature is suggested as additional background information: Guide E 94 and ANSI documents PH2.19 and PH2.36.

2. Referenced Documents

2.1 *ASTM Standards*:

E 94 Guide for Radiographic Testing

E 1316 Terminology for Nondestructive Examinations

2.2 *ANSI Documents*:

ANSI/NAPM IT2.19-1994, Photography — Density Measurements — Part 2: Geometric Conditions for Transmission Density

ANSI/NAPM IT2.16-1996, Photography — Density Measurements — Part 1: Terms, Symbols, and Notations

3. Terminology

3.1 *Definitions* — For definitions of terms used in this practice, see Terminology E 1316.

4. Significance and Use

4.1 This practice provides a means for calibrating transmission densitometers used for the measurement of radiographic film density. A transmission densitometer calibrated in accordance with this practice provides the assurance that accurate density values of radiographs are obtained.

5. Apparatus

5.1 Apparatus should consist of the following:

5.1.1 A calibrated step tablet shall be used. The step tablet may be a NIST X-ray Step Tablet (Standard Reference Material SRM 1001) or alternately a step tablet from another supplier, which is traceable to the NIST SRM 1001 X-ray Step Tablet. The step tablet shall have at least five step densities ranging from 0.3 through 3.9. The step tablet may have additional step densities less than 0.3 and greater than 3.9. A calibration certificate shall be provided with the step tablet indicating the tablet ID and recorded values for each step density. For suppliers of step tablets other than NIST, the certificate shall indicate conformance of traceability to NIST instrumentation used in the calibration process, applicable ANSI standards used, verification of measurement on a NIST SRM 1001 step tablet, the ID number of the SRM 1001 step tablet, and calibration date of the step tablet. Precautions should be taken in the storage, handling, and use of the step tablet. In the event it becomes scratched, blemished, or exhibits other signs of deleterious wear, it should be replaced immediately. The step tablet shall be replaced four years from date of first use.

5.1.2 *Transmission Densitometers*, with either direct-scale readout or digital readout displays specifi-

cally manufactured for the purpose of measuring the range of film densities described in 5.1.1 may be used.

5.1.3 *Manufacturer's Operating Instructions for Appropriate Transmission Densitometer.*

6. Calibration

6.1 Full-scale linearity calibration should be performed at least every 90 days during use as follows:

6.1.1 Allow a minimum of 30-min "warm-up" time (or the manufacturer's recommended warm-up time) to stabilize circuitry before starting the calibration procedure or the periodic verification checks described in Section 8. Adjust the "0" reading of the densitometer after the warm-up period.

6.1.2 Select and position for reading the neutral density closest to 0.3, 3.0, and 3.9 on the calibrated step tablet. Read and record the density for each step.

6.1.3 Compare the densities recorded with the actual density values on the calibrated step tablet or the density values listed on the calibration certificate. If the densitometer has been calibrated properly, the densities at 0.3, 3.0, and 3.9 steps should not vary more than ±0.05 density units. If any of the recorded density values vary more than ±0.05 density units from the density values on the calibrated step tablet, the linearity of the densitometer is out of tolerance and should be corrected.

7. Records and Associated Documentation

7.1 Note and record the calibrated readings, required by 6.1.2 in an appropriate calibration log. A pressure-sensitive label or tag that indicates the date the calibration was performed, and the identification of the individual performing the calibration, may be applied to the densitometer to verify the calibration reference check recorded in the calibration log.

7.2 An alternative calibration documentation system may be used provided the calibration traceability requirements identified in 7.1 can be satisfied and documented properly.

8. Periodic Verification

8.1 Periodic calibration verification checks using the procedure described in Section 6 should be performed at the beginning of each shift, after 8 h of continuous operation, or change of apertures, whichever occurs first.

8.1.1 If the verification reading is within ±0.05 of the density values recorded in the calibration log required by 7.1, the densitometer is ready for continued use. It is not necessary to record density values when they are within the acceptable tolerance. If the density values are not within the tolerance, recalibration is required and it shall be performed in accordance with Section 6.

8.1.2 If the calibration verification check shows a variation greater than ±0.05, then all radiographs examined since the last acceptable daily density check should be subject to a reverification for density after the densitometer has been recalibrated.

8.2 Consult the Manufacturer's Technical Manual for troubleshooting information.

9. Keywords

9.1 calibration; densitometer; density; periodic verification; radiographic film

STANDARD TEST METHOD FOR DETERMINING THE FOCAL SIZE OF IRIDIUM-192 INDUSTRIAL RADIOGRAPHIC SOURCES

SE-1114

[Identical with ASTM Specification E 1114-92 (R1997)]

1. Scope

1.1 This test method covers the determination of the focal size of an iridium-192 radiographic source. The determination is based upon measurement of the image of the iridium metal source in a projection radiograph of the source assembly and comparison to the measurement of the image of a reference sample in the same radiograph.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 999 Guide for Controlling the Quality of Industrial Radiographic Film Processing

E 1316 Terminology for Nondestructive Testing

3. Terminology

3.1 For definitions of terms relating to this test method, refer to Terminology E 1316.

4. Significance and Use

4.1 One of the factors affecting the quality of a radiographic image is geometric unsharpness. The degree of geometric unsharpness is dependent upon the focal size of the source, the distance between the source and the object to be radiographed, and the distance between the object to be radiographed and the film. This test method allows the user to determine the focal size of the source and to use this result to establish source to object and object to film distances appropriate for maintaining the desired degree of geometric unsharpness.

5. Apparatus

5.1 *Subject Iridium-192 Source,* the focal size of which is to be determined. The appropriate apparatus and equipment for the safe storage, handling, and manipulation of the subject source, such as a radiographic exposure device (also referred to as a gamma ray projector or camera), remote control, source guide tube, and source stop are also required.

5.2 *Reference Sample* (see Figs. 1,2, and 3) — The reference sample shall be of material which is not radioactive. The recommended material is iridium. However, substitutes such as platinum, tungsten, or other material of similar radiopacity may be used. The sample should be of the same geometric shape as the subject source, should be approximately the same size as the subject source, and should be positioned on or within a shim or envelope to simulate the source capsule wall. The resulting radiographic contrast, with reference to adjacent background density of the image of the reference sample, should be approximately the same as that of the subject source. The actual dimensions of the reference sample should be determined to the nearest 0.025 mm (0.001 in.).

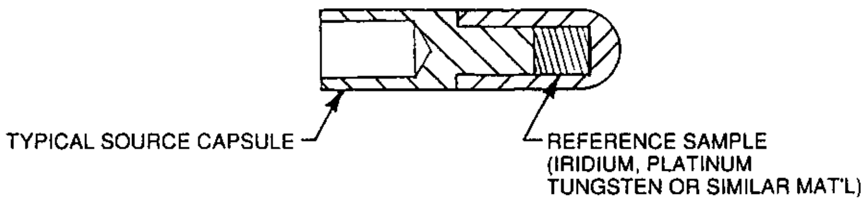


FIG. 1 REFERENCE SAMPLE IN STANDARD SOURCE ENCAPSULATION

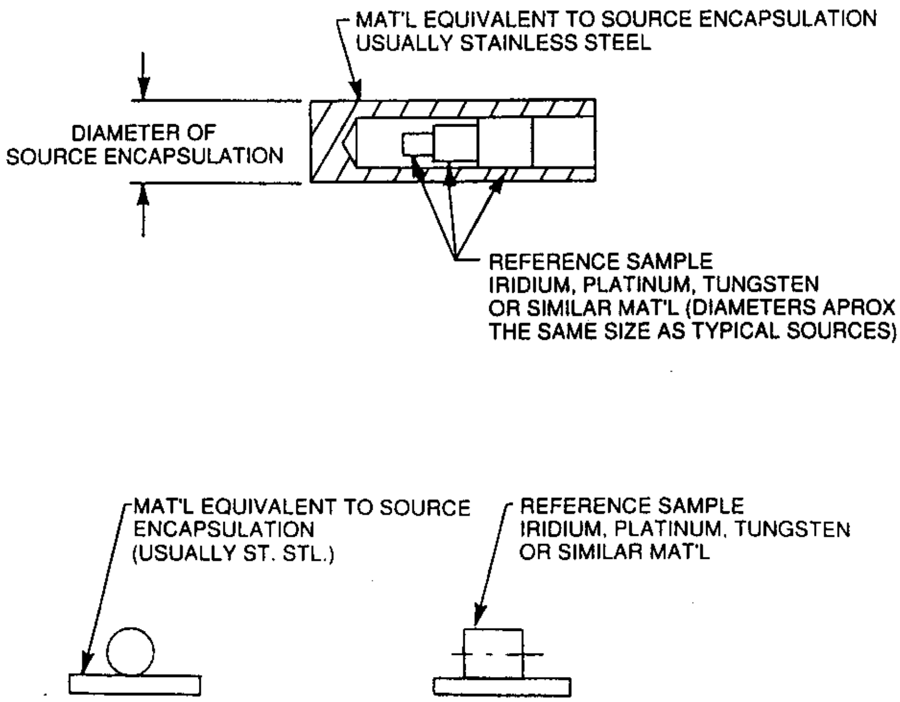


FIG. 2 ALTERNATE REFERENCE SAMPLE ARRANGEMENT

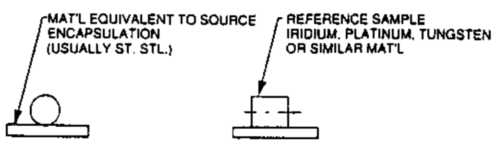


FIG. 3 ALTERNATE REFERENCE SAMPLE ARRANGEMENT

TABLE 1
EXAMPLES OF TYPICAL X-RAY GENERATOR OUTPUT REQUIREMENTS FOR RELATED IRIDIUM^{192} SOURCE ACTIVITIES

Subject Iridium^{192} Source Radiation			Typical X-ray Generator Output Requirements	
Activity (Curie)	Output (Rh at 1 m)		Potential	Current
30	14.4		160 kV	5 mA
		or	200 kV	3 mA
100	48.0		160 kV	10 mA
		or	250 kV	4 mA
200	96.0		160 kV	20 mA
		or	250 kV	8 mA
		or	300 kV	6 mA

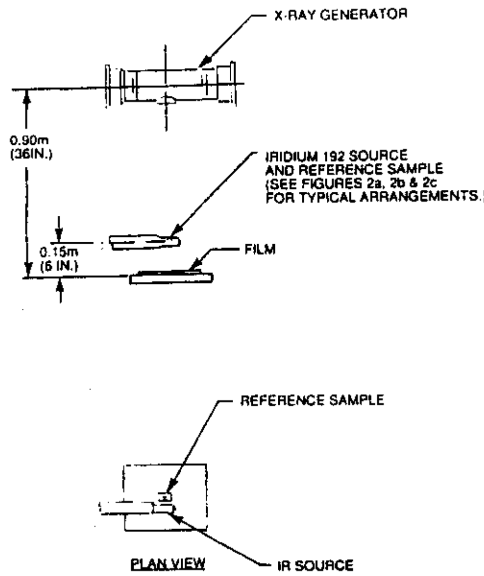


FIG. 4 TYPICAL EXPOSURE ARRANGEMENT

5.3 *X-ray Generator,* capable of producing a radiation intensity (roentgen per hour at one metre) at least ten times greater than that produced by the subject source. Examples of typical X-ray generator output requirements that satisfy this criterion are presented in Table 1.

5.4 *Film,* industrial type fine grain, extra fine grain, or ultra fine grain as defined by the film manufacturer shall be used. Selection of film type should be determined by such factors as the required radiographic quality level, equipment capability, materials, and so forth. The films selected must be capable of demonstrating the required image quality. No intensifying screens should be used. The film should be processed in accordance with Guide E 999.

5.5 *Image Measurement Apparatus* — This apparatus is used to measure the size of the image of the focal spot. The apparatus shall be an optical comparator with built-in graticule with 0.1 mm divisions or 0.001 in. divisions and magnification of 5× to 10×.

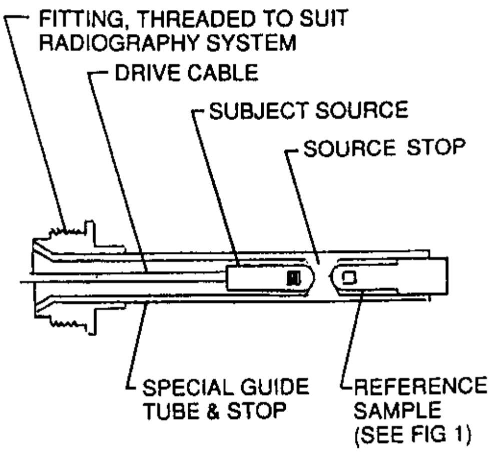


FIG. 5 TYPICAL ARRANGEMENT USING A SPECIALLY DESIGNED GUIDE TUBE

6. Procedure

6.1 Set up the exposure arrangement as shown in Figs. 4, 5, 6, and 7. Position the X-ray tube directly over the center of the film. The film plane must be normal to the central ray of the X-ray beam. The X-ray focal spot should be 0.90 m (36 in.) from the film. Position the reference sample and apparatus used to locate the subject source (source stop) as close together as possible and directly over the center of the film. The plane of the source stop and reference sample must be parallel to the film and normal to the central ray of the X-ray beam. The source stop and reference sample should be 0.15 m (6 in.) from the film. The source stop should be connected to the radiographic exposure device by the shortest source guide tube practicable in order to minimize fogging of the film during source transit.

6.2 Place identification markers to be imaged on the film to identify, as a minimum, the identification (serial number) of the subject source, the size of the reference

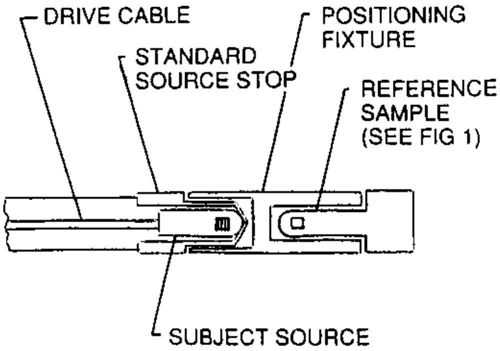


FIG. 6 TYPICAL ARRANGEMENT USING A STANDARD GUIDE TUBE AND SPECIAL POSITIONING FIXTURE

sample, the identification of the organization performing the determination, and the date of the determination. Care should be taken to ensure that the images of the subject source and reference sample will not be superimposed on the image of the identification markers.

6.3 *Exposure* — Select the X-ray tube potential (kV), X-ray tube current (mA), and exposure time such that the density in the image of the envelope surrounding the reference sample does not exceed 3.0 and that the density difference between the image of the reference sample and the image of the envelope surrounding the reference sample is at least 0.10.

NOTE — The actual parameters that will produce acceptable results may vary between X-ray units, and trial exposures may be necessary.

6.3.1 Energize the X-ray generator and, at the same time, manipulate the subject source into the exposure position in the source stop. It is important that this be performed as quickly as possible to minimize fogging of the film.

6.3.2 At the conclusion of the exposure time, deenergize the X-ray generator and, at the same time, return the subject source to the proper shielded storage position.

6.3.3 Process the film.

7. Measurement of Focal Dimensions

7.1 View the radiograph with sufficient light intensity for adequate viewing. Using an optical comparator with built-in graticule as described in 5.5, measure the linear dimensions of the image of the focal spot of the subject source and the reference sample. Take measurements from the perceptible edges of the image. When performing the physical measurements with the optical comparator, the actual measured values shall be to the nearest graduation on the graticule scale being used.

7.2 The focal size for a given technique is the maximum projected dimension of the source in the plane perpendicular to a line drawn from the source to the object being radiographed. Therefore, sufficient measurements of the image of the iridium must be made to determine the focal size of the source in any orientation. Sections 7.2.1 through 7.2.4 serve as examples.

7.2.1 *Uniform Right Circular Cylinder* (see Fig. 8) — Determine the focal size of a uniform right circular cylindrical source by measuring the diameter, d, the height, h, and the diagonal, m, as illustrated in Fig. 8 and computing the actual dimensions as described in 8.1.

7.2.2 *Sphere* (see Fig. 9) — Determine the focal size of a spherical source by measuring the diameter, d, as illustrated in Fig. 9 and computing the actual dimension as described in 8.1.

7.2.3 *Nonuniform Stack of Right Circular Cylinders* (see Fig. 10) — Determine the focal size of a nonuniform stack of right circular cylindrical components of a source by measuring the intrinsic diameter, d, the height, h, and the effective maximum dimension, m, as illustrated in Fig. 10 and computing the actual dimensions as described in 8.1.

7.2.4 *Separated Stack of Right Circular Cylinders* (see Fig. 11) — Determine the focal size of a separated stack of right circular cylindrical components of a source by measuring the intrinsic diameter, d, the effective height, h, and the effective maximum dimension, m, as illustrated in Fig. 11 and computing the actual dimensions as described in 8.1.

8. Calculation and Evaluation

8.1 Measure the linear dimension of interest in the subject source image and measure the same linear dimension in the reference sample image (that is, the diameter of each). The actual dimension of the subject source is computed from the following:

$$a = \frac{bc}{d}$$

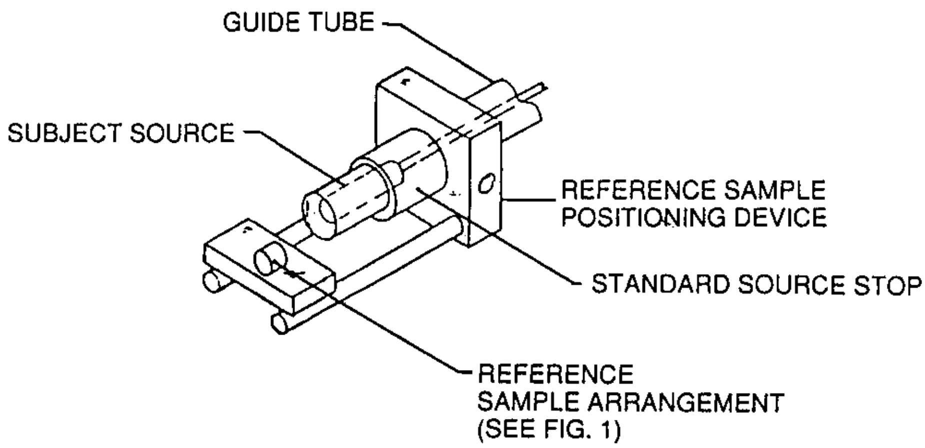


FIG. 7 TYPICAL ARRANGEMENT USING REFERENCE SAMPLE POSITIONING DEVICE

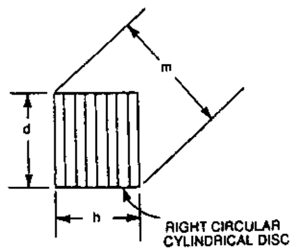


FIG. 8 UNIFORM RIGHT CIRCULAR CYLINDER

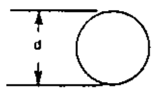


FIG. 9 SPHERE

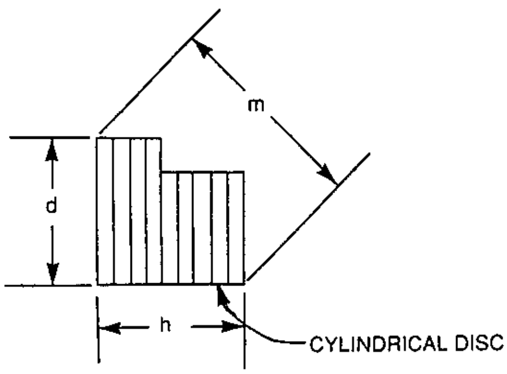


FIG. 10 NONUNIFORM CYLINDRICAL STACK

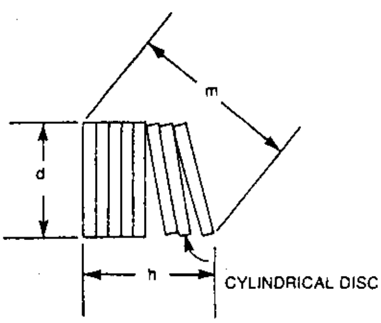


FIG. 11 SEPARATED CYLINDRICAL STACK

where:

a = actual dimension of the subject source,
b = actual dimension of the reference sample,
c = measured dimension of the subject source image, and
d = measured dimension of the reference sample image.

9. Report

9.1 A report of the focal size of an iridium-192 source should indicate the model number and serial number of the source, the name of the organization making the determination, the date the determination was made, a description of the shape of the source (or an appropriate sketch), and the calculated actual dimensions. The actual radiograph should accompany the report.

10. Keywords

10.1 cylinder(s); focal size; iridium 192; radiographic source; reference sample; sphere

STANDARD TEST METHOD FOR MEASUREMENT OF FOCAL SPOTS OF INDUSTRIAL X-RAY TUBES BY PINHOLE IMAGING

SE-1165

[Identical with ASTM Specification E 1165-92 (R1996)]

1. Scope

1.1 This test method provides instructions for determining the length and width dimensions of line focal spots in industrial X-ray tubes (see Note 1). This determination is based on the measurement of an image of a focal spot that has been radiographically recorded with a "pinhole" projection/imaging technique.

NOTE 1 — Line focal spots are associated with vacuum X-ray tubes whose maximum voltage rating does not generally exceed 500 kV.

1.2 This test method may not yield meaningful results on focal spots whose nominal size is less than 0.3 mm (0.011 in.). (See Note 2.)

NOTE 2 — The X-ray tube manufacturer may be contacted for nominal focal spot dimensions.

1.3 This test method may also be used to determine the presence or extent of focal spot damage or deterioration that may have occurred due to tube age, tube overloading, and the like. This would entail the production of a focal spot radiograph (with the pinhole method) and an evaluation of the resultant image for pitting, cracking, and the like.

1.4 Values stated in SI units are to be regarded as the standard. Inch-pound units are provided for information only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Document

2.1 *ASTM Standard:*

E 999 Guide for Controlling the Quality of Industrial Radiographic Film Processing

3. Terminology

3.1 *Definitions of Terms Specific to This Standard*

3.1.1 *actual focal spot* — the X-ray producing area of the target as viewed from a position perpendicular to the target surface (see Fig. 1).

3.1.2 *effective focal spot* — the X-ray producing area of the target as viewed from a position perpendicular to the tube axis in the center of the X-ray beam (see Fig. 1).

3.1.3 *line focal spot* — a focal spot whose projected pinhole image consists primarily of two curved lines (see Fig. 2).

4. Significance and Use

4.1 One of the factors affecting the quality of a radiographic image is geometric unsharpness. The degree of geometric unsharpness is dependent upon the focal size of the radiation source, the distance between the source and the object to be radiographed, and the distance between the object to be radiographed and the film. This test method allows the user to determine the focal size of the X-ray source and to use this result to establish source to object and object to film distances appropriate for maintaining the desired degree of geometric unsharpness.

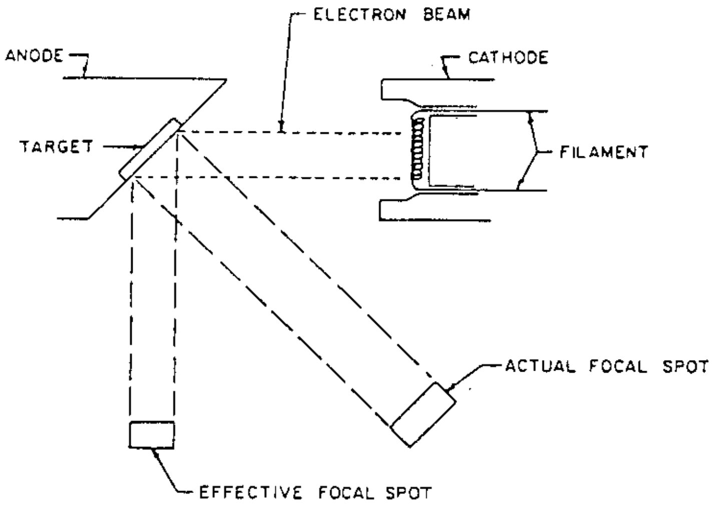
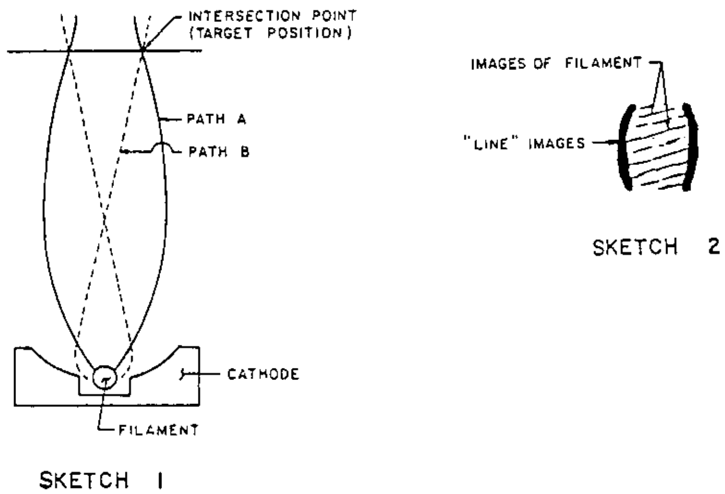


FIG. 1 ACTUAL/EFFECTIVE FOCAL SPOT



NOTE—During the production of X-rays the electrons are accelerated from the filament to the target in two separate paths (see Sketch 1). Electrons emitted at the front of the filament travel primarily along Path A, and electrons emitted at the backside of the filament travel primarily along Path B. Note that these two paths intersect at a certain point; this is the point at which the target is positioned. As a result, the pinhole picture of the focal spot shows two lines that correspond with the intersections of Paths A and B at the target (see Sketch 2).

FIG. 2 LINE FOCAL SPOT

TABLE 1
PINHOLE DIAPHRAGM DESIGN REQUIREMENTS (DIMENSION)[A]

NOTE — The pinhole diaphragm shall be made from one of the following materials:
(1) An alloy of 90% gold and 10% platinum,
(2) Tungsten,
(3) Tungsten carbide,
(4) Tungsten alloy,
(5) Platinum and 10% Iridium alloy, or
(6) Tantalum.

Nominal Dimension of Focal Spot, mm (in.)[B]	Nominal Diameter of Diaphragm Opening, mm (in.)	Required "D" and "L" Dimensions, mm (in.)	
		D	L
>0.3 to 1.2 (0.011 to 0.046) incl	0.030 (0.0011)	0.030 ± 0.005 (0.0011 ± 0.0002)	0.075 ± 0.010 (0.0029 ± 0.0004)
>1.2 to 2.5 (0.046 to 0.097) incl	0.075 (0.0029)	0.075 ± 0.005 (0.0029 ± 0.0002)	0.350 ± 0.010 (0.014 ± 0.0004)
>2.5 (0.097)	0.100 (0.0039)	0.100 ± 0.005 (0.0039 ± 0.0002)	0.500 ± 0.010 (0.02 ± 0.0004)

[A] See Fig. 3.
[B] Nominal focal spot dimensions may be obtained from the X-ray tube manufacturer.

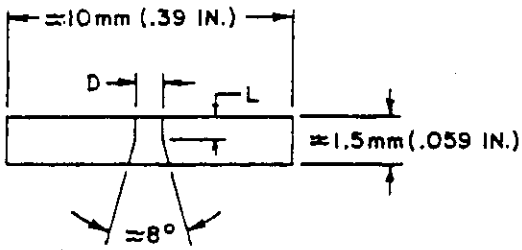


FIG. 3 PINHOLE DIAPHRAGM DESIGN

5. Apparatus

5.1 *Pinhole Diaphragm* — The pinhole diaphragm shall conform to the design and material requirements of Table 1 and Fig. 3.

5.2 *Camera* — The pinhole camera assembly consists of the pinhole diaphragm, the shielding material to which it is affixed, and any mechanism that is used to hold the shield/diaphragm in position (jigs, fixtures, brackets, and the like; see Fig. 4).

5.3 *Film* — Industrial type extra fine grain. No intensifying screens are to be used. The film shall be processed in accordance with Guide E 999.

5.4 *Image Measurement Apparatus* — This apparatus is used to measure the size of the image of the focal spot. The apparatus shall be an optical comparator with built-in graticule with 0.1 mm or 0.001 in., or both divisions and magnification of 5× to 10× (or equivalent).

6. Procedure

6.1 If possible, use a standard 91.44 cm (36 in.) focal spot to film plane distance (FFD) for all exposures. If machine geometry or accessibility limitations will not permit the use of a 91.44 cm (36 in.) FFD, use the maximum attainable FFD (in these instances adjust the relative distances between focal spot, pinhole, and film accordingly to suit the image enlargement factors specified in Table 2). The distance between the focal spot and the pinhole is based on the nominal size of the focal spot being measured and the desired degree of image enlargement (see Fig. 5). The specified focal spot to pinhole distance (FHD) for the different nominal focal spot size ranges is provided in Table 2. Position the pinhole such that it is within ±1° of the central axis of the X-ray beam. Fig. 6 illustrates a typical focal spot exposure arrangement.

NOTE 3 — The accuracy of the pinhole system is highly dependent upon the relative distances between (and alignment of) the focal spot, the pinhole, and the film. Accordingly, specially designed apparatus may be necessary in order to assure compliance with the above requirements. Figure 7 provides an example of a special collimator that can be used to ensure conformance with the ±1° alignment tolerance. Some other standards impose very stringent alignment requirements and express these requirements in terms of radial tolerances. These documents do not, however, address any means for assuring compliance with such tolerances. In order to simplify the focal spot radiography technique and to improve the

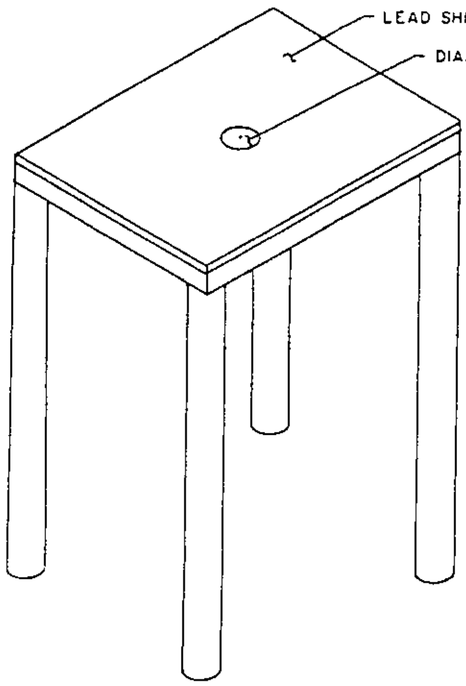


FIG. 4 PINHOLE CAMERA (TYPICAL)

TABLE 2
IMAGE ENLARGEMENT FACTORS

Nominal Focal Spot Size, mm (in.)	Enlargement Factor	Distance Between Focal Spot and Pinhole (FHD), cm (in.)[A]
0.3 to 1.2 (0.011 to 0.046) incl	3×	22.9 (9)
>1.2 to 2.5 (0.046 to 0.097) incl	2×	30.5 (12)
>2.5 (0.097)	1×	45.7 (18)

[A] When using a technique that entails the use of enlargement factors and a 91.44 cm (36 in.) focal spot to film distance (FFD) is not possible (see 6.1), the distance between the focal spot and the pinhole (FHD) shall be adjusted to suit the actual focal spot to film distance (FFD) used [for example, if a 61 cm (24 in.) FFD is used, the FHD shall be 15.25 cm (6 in.) for 3× enlargement, 20.32 cm (8 in.) for 2× enlargement, and the like].

overall practicality of the procedure, it is considered that a workable alignment tolerance, and a means of assuring conformance with that tolerance, is appropriate. Accordingly, this standard addresses tolerances in angular terms and provides a method for assuring compliance with these tolerances. This provides a practical means of meeting the precision and bias requirements of Section 9.

6.2 Position the film as illustrated in Fig. 6. The exposure identification appearing on the film (by radiographic imaging) should be X-ray machine identity (that is, make and serial number), organization making the radiograph, and date of exposure.

6.3 Adjust the kilovoltage and milliamperage settings on the X-ray machine to that specified in Table 3.

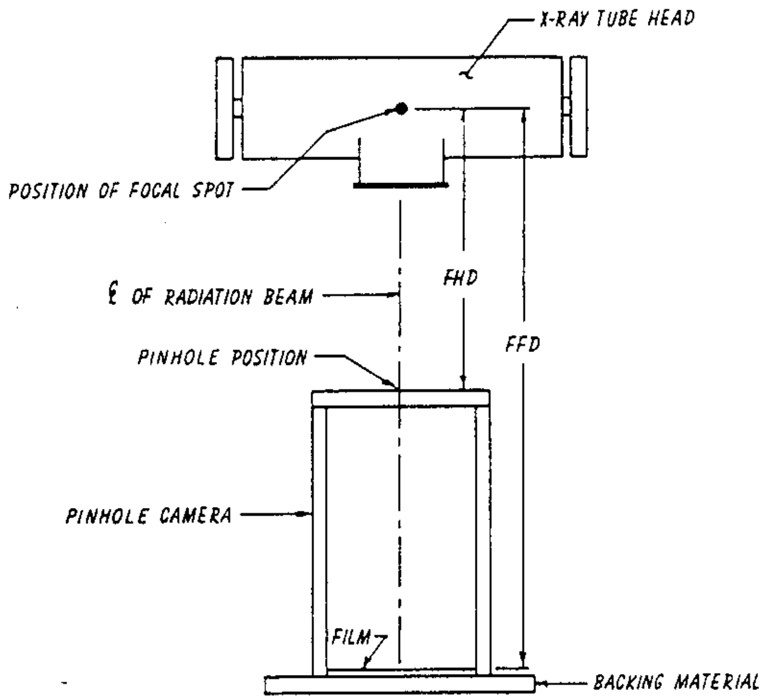
6.4 Expose the film such that the density of the darkest portion of the focal spot image conforms to the limits specified in Table 4. Density measurement shall be as illustrated in Fig. 8. Density shall be controlled by exposure time only.

6.5 Process the film in accordance with Guide E 999.

6.6 *Focal Spot Measurement:*

6.6.1 *Back Lighting* — Back lighting shall be such that the focal spot image can be easily and comfortably viewed.

6.6.2 Place the magnification graticule (handheld optical comparator) in intimate contact with the film for the measurement determination. Determine an imaginary "box" that represents the perceptible edges of the focal spot image [see Fig. 9(a)] for the extremities measurement.



FFD = 91.44 cm (36 in.)
FHD = 22.86 cm (9 in.) for 3X enlargement
30.48 cm (12 in.) for 2X enlargement
45.72 cm (18 in.) for 1X enlargment

NOTE—See 6.1 and Table 1 if a 91.44 cm (36 in.) FFD is not achievable.

FIG. 5 SCHEMATIC OF FHD/FFD RELATIONSHIP

6.6.3 Measure the focal spot image in two directions [see Fig. 9(b)]:

6.6.3.1 Direction A — Parallel to the axis of the tube.

6.6.3.2 Direction B — Perpendicular to the axis of the tube.

7. Calculation of Results

7.1 Multiply the measured "A" direction dimension by a correction factor of 0.7 to determine the actual "A" dimension (see Note 4). The measured "B" direction dimension is representative of actual size.

NOTE 4 — The need for the 0.7 fractional multiplier for correction of the measured image length arises from the fact that the lengthwise distribution of energy in the focal spots of line-focus tubes tends to be peaked in the center and diminishes gradually to zero at the ends. Hence, the effective length, (that is, resultant effect on radiographic definition and film density distribution) cannot be stated as equal to the measured length.

7.2 If an image enlargement technique was used, divide the "A" and "B" direction measurements by the pertinent enlargement factor to obtain actual focal spot size (see Fig. 5 and Table 2).

8. Report

8.1 A report documenting the focal spot size determination should include the machine model number and serial number, the X-ray tube serial number, the focal spot(s) that was measured (some machines have dual focal spots), the set-up and exposure parameters (for example, kilovoltage, milliamps, enlargement factor, and the like) date, name of organization, and estimated beam time hours (if available).

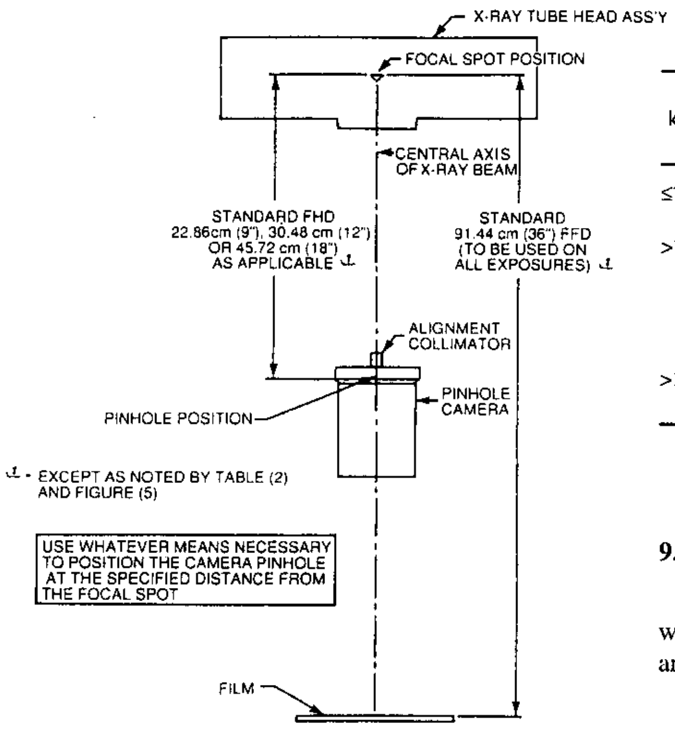


FIG. 6 EXPOSURE SET-UP SCHEMATIC

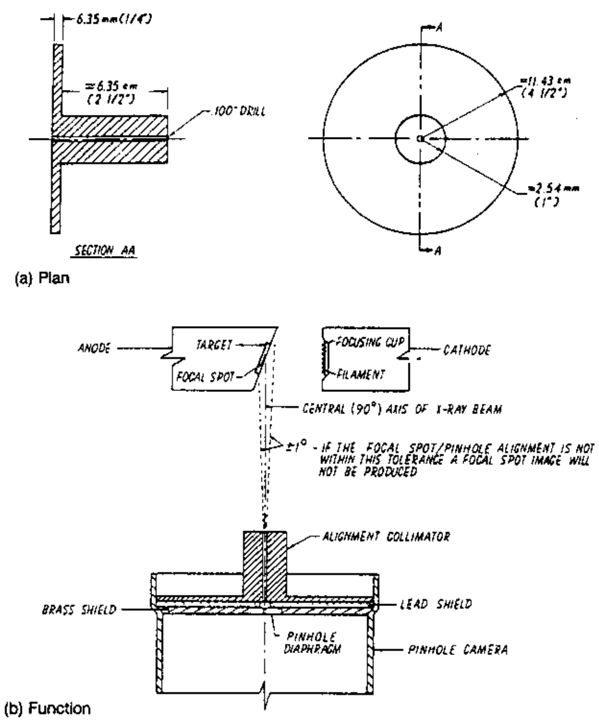


FIG. 7 ALIGNMENT COLLIMATOR

TABLE 3
TEST VOLTAGE AND CURRENT

kVp Rating of X-Ray Machine	Voltage To Be Used for Focal Spot Radiography	Current To Be Used for Focal Spot Radiography
≤75 kV	maximum rated voltage	
>75 kV to 150 kV	75 kV	50% of maximum permissible current at the test voltage utilized
>150 kV	50% of maximum rated voltage	

9. Precision and Bias

9.1 Conformance to the requirements specified herein will produce results that are within the following tolerances:

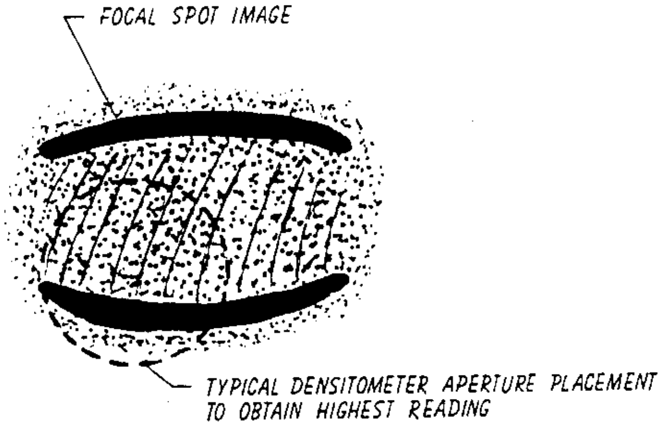
9.1.1 *Technique* — The technique requirements specified herein will produce a focal spot image whose size is ±5% of the actual effective focal spot size.

9.1.2 *Measurement* — The measurement requirements specified herein will produce results that are within the tolerances:

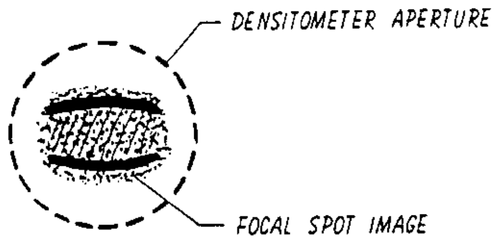
Nominal Focal Spot Size, mm (in.)	Measurement Tolerances
0.3 to 1.2 (0.011 to 0.046) incl	±30%
>1.2 to 2.5 (0.046 to 0.097) incl	±25%
>2.5 (0.097)	±20%

10. Keywords

10.1 focal spots; pinhole camera; pinhole imaging; x-ray; x-ray tube



NOTE—For instances where the focal spot image is larger than the densitometer aperture, measure the density in several places to determine the darkest area.

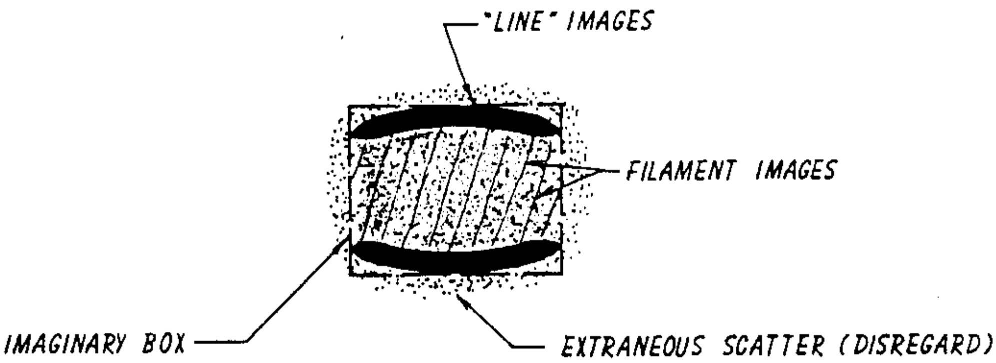


NOTE—For instances where the focal spot image is smaller than the densitometer aperture, center the focal spot image in the densitometer aperture area.

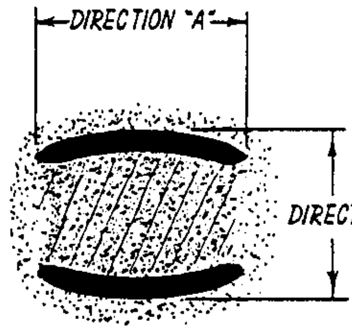
FIG. 8 FOCAL SPOT DENSITY MEASUREMENT

TABLE 4
DENSITY RANGE FOR DARKEST AREA OF FOCAL SPOT IMAGE (See Fig. 7)

Transmission Densitometer Aperture Diameter, mm (in.)	For images whose minimum dimension is less than 2 mm (0.078 in.)	For images whose minimum dimension is greater than 2 mm (0.078 in.)
1 (0.039)	0.8 to 2.0 density	1.0 to 3.0 density
2 (0.078)	0.5 to 1.8 density	1.0 to 3.6 density



(a) Imaginary "Box" That Represents the Perceptible Edges of the Focal Spot Image



(b) Measurement Direction

FIG. 9 FOCAL SPOT IMAGE

STANDARD PRACTICE FOR RADIOSCOPY

SE-1255

(Identical with ASTM Specification E 1255-96)

1. Scope

1.1 This practice provides application details for radioscopic examination using penetrating radiation. This includes dynamic radioscopy and for the purposes of this practice, radioscopy where there is no motion of the test object during exposure (referred to as static radioscopic imaging). Since the techniques involved and the applications for radioscopic examination are diverse, this practice is not intended to be limiting or restrictive, but rather to address the general applications of the technology and thereby facilitate its use. Refer to Guides E 94 and E 1000, Terminology E 1316, Practice E 747, Practice E 1025, and Fed. Std. Nos. 21 CFR 1020.40 and 29 CFR 1910.96 for a list of documents that provide additional information and guidance.

1.2 The general principles discussed in this practice apply broadly to penetrating radiation radioscopic systems. However, this document is written specifically for use with X-ray and gamma-ray systems. Other radioscopic systems, such as those employing neutrons, will involve equipment and application details unique to such systems.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific safety statements, see Section 8 and Fed. Std. Nos. 21 CFR 1020.40 and 29 CFR 1910.96.

2. Referenced Documents

2.1 *ASTM Standards:*

E 94 Guide for Radiographic Testing

E 747 Practice for Design, Manufacture, and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology

E 1000 Guide for Radioscopy

E 1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology

E 1316 Terminology for Nondestructive Examinations

2.2 *ASNT Standard:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *Federal Standards:*

21 CFR 1020.40 Safety Requirements of Cabinet X-Ray Systems

29 CFR 1910.96 Ionizing Radiation

2.4 *National Council on Radiation Protection and Measurement (NCRP) Standard:*

NCRP 49 Structural Shielding Design and Evaluation for Medical Use of X-Rays and Gamma Rays of Energies up to 10 MeV

3. Summary of Practice

3.1 Manual evaluation as well as computer-aided automated radioscopic examination systems are used in a wide variety of penetrating radiation examination applications. A simple manual evaluation radioscopic examination system might consist of a radiation source and a directly viewed fluorescent screen, suitably enclosed in a radiation protective enclosure. At the other extreme, a complex automated radioscopic examination system might consist of an X-ray source, a robotic test part manipulator, a radiation protective enclosure, an electronic image detection system, a closed-circuit television image transmission system, a digital image processor, a video display, and a digital image archiving system. All system components are supervised by the host computer, which incorporates the software neces-

sary to not only operate the system components, but to make accept/reject decisions as well. Systems having a wide range of capabilities between these extremes can be assembled using available components. Guide E 1000 lists many different system configurations.

3.2 This practice provides details for applying radioscopic examination techniques, however, supplemental requirements are necessary to address areas that are application and performance specific. Annexes A1 and A2 provide the detailed supplemental requirements for government contracts (Annex A1) and nongovernment contracts (Annex A2).

4. Significance and Use

4.1 As with conventional radiography, radioscopic examination is broadly applicable to any material or test object through which a beam of penetrating radiation may be passed and detected including metals, plastics, ceramics, composite, and other nonmetallic materials. In addition to the benefits normally associated with radiography, radioscopic examination may be either a dynamic, filmless technique allowing the test part to be manipulated and imaging parameters optimized while the test object is undergoing examination, or a static, filmless technique wherein the test part is stationary with respect to the X-ray beam. Recent technology advances in the area of projection imaging, detectors, and digital image processing provide acceptable sensitivity for a wide range of applications.

5. Equipment and Procedure

5.1 *System Configuration* — Many different radioscopic examination system configurations are possible, and it is important to understand the advantages and limitations of each. It is important that the optimum radioscopic examination system be selected for each examination requirement through a careful analysis of the benefits and limitations of the available system components and the chosen system configuration. The provider as well as the user of the radioscopic examination services should be fully aware of the capabilities and limitations of the radioscopic examination system that is proposed for examination of the test object. The provider and the user of radioscopic examination services shall agree upon the system configuration to be used for each radioscopic examination application under consideration, and how its performance is to be evaluated.

5.1.1 The minimum radioscopic examination system configuration will include an appropriate source of penetrating radiation, a means for positioning the test object within the radiation beam, in the case of dynamic radioscopy, and a detection system. The system may be as simple as a directly viewed fluorescent screen with suitable radiation shielding for personnel protection that meets applicable radiation safety codes.

5.1.2 A more complex system might include the following components:

5.1.2.1 A microfocus X-ray system to facilitate high-resolution projection imaging;

5.1.2.2 A multiple axis test part manipulation system to provide dynamic, full volumetric test part manipulation under operator joystick or automated program control, for dynamic radioscopy;

5.1.2.3 An electronic imaging system to display a bright, two-dimensional gray-scale image of the test part at the operator's control console;

5.1.2.4 A digital image processing system to perform image enhancement and image evaluation functions;

5.1.2.5 An archival quality image recording system; and

5.1.2.6 A radiation protective enclosure with appropriate safety interlocks and a radiation warning system.

5.1.3 Whether a simple or a complex system is used, the system components and configuration utilized to achieve the prescribed test results must be carefully selected.

5.2 *Practice:*

5.2.1 The purchaser and supplier for radioscopic examination services shall mutually agree upon a written procedure using the applicable annex of supplemental requirements and also consider the following general requirements.

5.2.1.1 *Equipment Qualifications* — A listing of the system features that must be qualified to ensure that the system is capable of performing the desired radioscopic examination task.

5.2.1.2 *Test Object Scan Plan* — A listing of test object orientations, ranges of motions, and manipulation speeds through which the test object must be manipulated to ensure satisfactory examination.

5.2.1.3 *Radioscopic Parameters* — A listing of all the radiation source–related variables that can affect the examination outcome for the selected system configuration such as: source energy, intensity, focal spot size, range of source to object distances, range of object to image plane distances, and source to image plane distances.

5.2.1.4 *Image Processing Parameters* — A listing of all the image processing variables necessary to enhance fine detail detectability in the test object and to achieve the required sensitivity level. These would include, but are not limited to, techniques such as noise reduction, contrast enhancement, and spatial filtering. Great care should be exercised in the selection of directional image processing parameters such as spatial filtering, which may emphasize features in certain orientations and suppress them in others. The listing should indicate the means for qualifying image processing parameters.

5.2.1.5 *Image Display Parameters* — A listing of the techniques and the intervals at which they are to be applied for standardizing the video image display as to brightness, contrast, focus, and linearity.

5.2.1.6 *Accept/Reject Criteria* — A listing of the expected kinds of test object imperfections and the rejection level for each.

5.2.1.7 *Performance Evaluation* — A listing of the qualification tests and the intervals at which they are to be applied to ensure that the radioscopic examination system is suitable for its intended purpose.

5.2.1.8 *Image Archiving Requirements* — A listing of the requirements, if any, for preserving a historical record of the examination results. The listing may include examination images along with written or electronically recorded alpha-numeric or audio narrative information, or both, sufficient to allow subsequent reevaluation or repetition of the radioscopic examination.

5.2.1.9 *Operator Qualifications* — Nondestructive testing (NDT) personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or a standard such as ANSI/ASNT CP-189, SNT-TC-1A, MIL-STD-410, or a similar document, to the level appropriate for the peformance of the listed radioscopic examination.

6. Radioscopic Examination System Performance Considerations and Measurement

6.1 *Factors Affecting System Performance* — Total radioscopic examination system performance is determined by the combined performance of the system components, which include the radiation source, manipulation system (for dynamic radioscopy), detection system, information processing system, image display, automatic evaluation system, and examination record archiving system.

6.1.1 *Radiation Sources* — While the radioscopic examination systems may utilize either radioisotope or X-ray sources, X-radiation, is used for most radioscopic examination applications. This is due to the energy spectrum of the X-radiation, which contains a blend of contrast-enhancing longer wavelengths, as well as the more penetrating, shorter wavelengths. X-radiation is adjustable in energy and intensity to meet the radioscopic examination test requirements, and has the added safety feature of discontinued radiation production when switched off. A radioisotope source has the advantages of small physical size, portability, simplicity, and uniformity of output.

6.1.1.1 X-ray machines produce a more intense X-ray beam emanating from a smaller focal spot than do radioisotope sources. X-ray focal spot sizes range from a few millimeters down to a few micrometers. Reducing the source size reduces geometric unsharpness, thereby enhancing detail sensitivity. X-ray sources may offer multiple or variable focal spot sizes. Smaller focal spots produce higher resolution and provide reduced X-ray beam intensity, while larger focal spots provide higher X-ray intensity and produce lower resolution. Microfocus X-ray tubes are available with focal spots that may be adjusted to as small as a few micrometers in diameter, while still producing an X-ray beam of sufficient intensity so as to be useful for the radioscopic examination of finely detailed test objects.

6.1.1.2 Conventional focal spots of 1.0 mm and larger are useful at low geometric magnification values close to 1×. Fractional focal spots ranging from 0.4 mm up to 1.0 mm are useful at geometric magnifications of up to approximately 2×. Minifocus spots in the range from 0.1 mm up to 0.4 mm are useful at geometric magnifications up to about 6×. Greater magnifications suggest the use of a microfocus spot size of less than 0.1 mm in order to minimize the effects of geometric unsharpness. Microfocus X-ray tubes are capable of focal spot sizes of less than 10 micrometers (10^{-8}

meters) and are useful for geometric magnifications of more than 100×.

6.1.2 *Manipulation System for Dynamic Radioscopy* — The test part manipulation system has the function of holding the test object and providing the necessary degrees of freedom, ranges of motion, and speeds of travel to position the test object areas of interest in the radiation beam in such a way so as to maximize the radioscopic examination system's response. In some applications it may be desirable to manipulate the radiation source and detection system instead of, or in addition to, the test object. The manipulation system must be capable of smooth well-controlled motion, especially so for high-magnification microfocus techniques, to take full advantage of the dynamic aspects of the radioscopic examination.

6.1.3 *Detection System* — The detection system is a key element. It has the function of converting the radiation input signal containing test part information, into a corresponding optical or electronic output signal while preserving the maximum amount of test object information. The detector may be of one-dimensional design, providing test part information one line at a time, or may be a two-dimensional area detector providing an area field of view.

6.1.4 *Information Processing of System:*

6.1.4.1 The function of the information processing system is to take the output of the detection system and present a useful image for display and operator interpretation, or for automatic evaluation. The information processing system may take many different forms, and may process analog or digital information, or a combination of the two.

6.1.4.2 The information processing system includes all of the optics, electronics, and interfaces after the detection system to and including the image display and automatic evaluation system. Information system components include such devices as lenses, fiber optic couplings, light amplifiers, video cameras, image processors, and in general any device that processes radioscopic examination information after the detection system.

6.1.4.3 The digital image processing system warrants special attention, since it is the means by which radioscopic examination information may be enhanced. Great care must be exercised in determining which image processing techniques are most beneficial for the particular application. Directional spatial filtering operations, for example, must be given special attention as certain feature orientations are emphasized while others are suppressed. While many digital image processing operations occur sufficiently fast to follow time-dependent radioscopic system variables, others do not. Some image processing operations require significant image acquisition and processing time, so as to limit the dynamic response of the radioscopic exam, in dynamic radioscopic systems.

6.1.5 *Automatic Evaluation System* — Some radioscopic examination applications can be fully automated including the accept/reject decision through computer techniques. The automatic evaluation system's response to various test object conditions must be carefully determined under actual operating conditions. The potential for rejecting good test objects and accepting defective test objects must be considered. Automatic evaluation system performance criteria should be mutually determined by the provider and user of radioscopic examination services.

6.1.6 *Image Display:*

6.1.6.1 The function of the image display is to convey radioscopic information about the test object to the system operator. For manual evaluation systems, the displayed image is used as the basis for accepting or rejecting the test object, subject to the operator's interpretation of the radioscopic image. The image display performance, size, and placement are important radioscopic system considerations.

6.1.6.2 When employing a television image presentation, vertical and horizontal resolution are often not the same. Therefore, the effect of raster orientation upon the radioscopic examination system's ability to detect fine detail, regardless of orientation, must be taken into account.

6.1.7 *Radioscopic Examination Record Archiving System* — Many radioscopic examination applications require an archival quality examination record of the radioscopic examination. The archiving system may take many forms, a few of which are listed in 6.1.7.1 through 6.1.7.11. Each archiving system has its own peculiarities as to image quality, archival storage properties, equipment, and media cost. The examination record archiving system should be chosen on the basis of these and other pertinent parameters, as agreed upon by the provider and user of radioscopic examination services. The reproduction quality of the archival method should be sufficient to demonstrate the same image quality as was used to qualify the radioscopic examination system.

6.1.7.1 Film or paper radiograph of the test object made under the same conditions as the radioscopic examination image;

6.1.7.2 Spot film camera used to photograph the examination image directly from the output of an X-ray image intensifier without the intervening television chain limitations;

6.1.7.3 Photograph of the actual image display;

6.1.7.4 Multiformat camera used to make a photograph of the examination image from the video signal;

6.1.7.5 Video hard copy device used to create a paper facsimile image from the video signal;

6.1.7.6 Laser print hard copy device used to create a film image from the scanned detector output;

6.1.7.7 Video tape recorder used to record the video signal on magnetic tape; characterized by long recording time at video frame rates; useful for capturing test part motion;

6.1.7.8 Digital recording on magnetic disk or tape used to store the image of the test object digitally, characterized by limited storage capacity at video frame rates, therefore limiting the ability to capture test part motion in dynamic radioscopic systems;

6.1.7.9 Digital recording on optical disk used to store the image of the test object digitally; offers larger storage capacity than magnetic disk or tape; consideration should be given to the type of optical storage because there are fundamentally two different types: magneto-optical where radiological data can be erased or altered, and write once read many times (WORM) where a common format is CD-ROM and the radiological data cannot be erased or altered after the disk is created.

6.1.7.10 Electronic digital memory such as ROM (read only memory) or EPROM (erasable programmable read only memory), characterized by relatively limited capacity; and

6.1.7.11 Hologram used to store high-density digital image data on film at high-information density.

6.1.8 *Examination Record Data* — The examination record should contain sufficient information to allow the radioscopic examination test to be reevaluated or duplicated. Examination record data should be recorded contemporaneously with the radioscopic examination image, and may be in writing or a voice narrative, providing the following minimum data:

6.1.8.1 Radioscopic examination system designation, test date, operator identification, operating turn or shift, and other pertinent test and customer data;

6.1.8.2 Specific test part data as to part number, batch, serial number, etc. (as applicable);

6.1.8.3 Test part orientation and examination site information by manipulation system coordinate data or by reference to unique test part features within the field of view; and

6.1.8.4 System performance monitoring by recording the results of the prescribed radioscopic examination system performance monitoring tests, as set forth in Section 5, at the beginning and end of a series of radioscopic examinations, not to exceed the interval set forth in 6.2.1 for system performance monitoring.

6.2 *Performance Measurement* — Radioscopic examination system performance parameters must be determined initially and monitored regularly to ensure consistent results. The best measure of total radioscopic examination system performance can be made with the system in operation, utilizing a test object similar to the test part under actual operating conditions. This indicates the use of an actual or simulated test object or calibration block containing actual or simulated features that must be reliably detected. Such a calibration block will provide a reliable indication of the radioscopic examination system's capabilities. Conventional wire- or plaque-type IQIs may be used in place of, or in addition to, the simulated test object or calibration block. Performance measurement methods are a matter of agreement between the provider and user of radioscopic examination services.

6.2.1 *Performance Measurement Intervals* — System performance measurement techniques should be standardized so that performance measurement tests may be readily duplicated at specified intervals. Radioscopic examination system performance should be evaluated at sufficiently frequent intervals, as may be agreed upon by the supplier and user of radioscopic examination services, to minimize the possibility of time-dependent performance variations.

6.2.2 *Measurement With IQIs* — Radioscopic examination system performance measurement using IQIs shall be in accordance with accepted industry standards describing the use of IQIs. The IQIs should be placed on the test object as close as possible to the region of interest. The use of wire-type IQIs should also take

into account the fact that the radioscopic examination system may exhibit asymmetrical sensitivity, in which case the wire diameter axis shall be oriented along the system's axis of least sensitivity. Selection of IQI thickness should be consistent with the test part radiation path length thickness.

6.2.3 *Measurement With a Calibration Block* — The calibration block may be an actual test object with known features that are representative of the range of features to be detected, or may be fabricated to simulate the test object with a suitable range of representative features. Alternatively, the calibration block may be a one-of-a-kind or few-of-a-kind reference test object containing known imperfections that have been verified independently. Calibration blocks containing known, natural defects are useful on a single-task basis, but are not universally applicable. Where standardization among two or more radioscopic examination systems is required, a duplicate manufactured calibration block should be used. The calibration blocks should approximate the test object as closely as is practical, being made of the same material with similar dimensions and features in the radioscopic examination region of interest. Manufactured calibration blocks should include features at least as small as those that must be reliably detected in the actual test objects in locations where they are expected to occur in the actual test object. Where features are internal to the test object, it is permissible to produce the calibration block in sections. Calibration block details are a matter of agreement between the user and supplier of radioscopic examination services.

6.2.3.1 *Use of a Calibration Block* — The calibration block should be placed into the radioscopic examination system in the same position as the actual test object and may be manipulated through the same range of motions through a given exposure for dynamic radioscopic systems as are available for the actual test object, so as to maximize the radioscopic examination system's response to the simulated imperfection.

6.2.3.2 *Radioscopic Examination Techniques* — (radiation beam energy, intensity, focal spot size, enlargement, digital image processing parameters, manipulation scan plan for dynamic radioscopic systems, scanning speed, and other system variables) utilized for the calibration block shall be identical to those used for the actual examination of the test object.

6.2.4 *Use of Calibrated Line Pair Test Pattern and Step Wedge:*

6.2.4.1 A calibrated line pair test pattern and step wedge may be used, if so desired, to determine and track radioscopic system performance in terms of spatial resolution and contrast sensitivity. The line pair test pattern is used without an additional absorber to evaluate system spatial resolution. The step wedge is used to evaluate system contrast sensitivity.

6.2.4.2 The step wedge must be made of the same material as the test part with steps representing 100%, 99%, 98%, and 97% of both the thickest and the thinnest material sections to be examined. The thinner steps shall be contiguous to their respective 100% section thicknesses in order to facilitate discerning the minimum visible thickness step. Other thickness steps are permissible upon agreement between the provider and the user of radioscopic services.

6.2.4.3 The line pair test pattern and the step wedge tests shall be conducted in a manner similar to the performance measurements for the IQI or the calibration block set forth in 6.2.2 and 6.2.3. It is permissible to adjust the X-ray energy and intensity to obtain a usable line pair test pattern image brightness. In the case of a radioisotope or X-ray generating system where the energy or intensity may not be adjusted, additional filtration may be added at the radiation source to reduce the brightness to a useful level. Contrast sensitivity shall be evaluated at the same energy and intensity levels as are used for the radioscopic technique.

6.2.4.4 A system that exhibits a spatial resolution of 3 line pairs/mm, a thin section contrast sensitivity of 3%, and a thick section contrast sensitivity of 2% may be said to have an equivalent performance level of 3%–2%–3 lp/mm.

6.2.4.5 The line pair test pattern and the step wedge may be used to make more frequent periodic system performance checks than required in accordance with 6.2.1. Resolution and contrast sensitivity checks must be correlated with IQI or calibration block performance measurements. This may be done by first evaluating system measurement in accordance with 6.2.2 or 6.2.3 and immediately thereafter determining the equivalent spatial resolution and contrast sensitivity values.

6.2.5 *Importance of Proper Environmental Conditions* — Environmental conditions conducive to human comfort and concentration will promote examination efficiency and reliability, and must be considered in the performance of manual evaluation radioscopic examination systems. A proper examination environment will take into account temperature, humidity, dust, lighting,

access, and noise level factors. Proper reduced lighting intensity is extremely important to provide for high-contrast glare-free viewing of radioscopic examination images.

7. Radioscopic Examination Interpretation and Acceptance Criteria

7.1 *Interpretation* — Interpretation may be done either by an operator in a manual evaluation radioscopic environment, or by means of a computer and appropriate software in the case of an automated radioscopic examination system. A hybrid environment may also be utilized whereby the computer and software present to the operator a recommended interpretation, which is then subject to the operator's final disposition.

7.2 *Operator* — The supplier and user should reach an agreement as to operator qualifications including duty and rest periods. Recommended Practice SNT-TC-1A sets forth three levels of nondestructive testing personnel qualifications that the radioscopic examination practitioner may find useful.

7.3 *Accept/Reject Criteria* — Accept/reject criteria are a matter of contractual agreement between the provider and the user of radioscopic examination services.

8. Records, Reports, and Identification of Accepted Material

8.1 Records and reports are a matter of agreement between the supplier and the user. If an examination record archiving requirement exists, refer to 6.1.8, which outlines the necessary information that should be a part of an archival examination record.

9. Safety Conditions

9.1 Radioscopic examination procedures shall be carried out under protective conditions so that personnel will not receive radiation dose levels exceeding that permitted by company, city, state, or national regulations. The recommendations of the National Committee on Radiation Protection should be the guide to radiation safety.

10. Keywords

10.1 analog; detector; digital; display; examination; image; manipulator; processor; radioscopy; source

ANNEXES

(Mandatory Information)

A1. DEPARTMENT OF DEFENSE CONTRACTS, SUPPLEMENTAL REQUIREMENTS

A1.1 Scope

A1.1.1 *Purpose* — This annex is to be used in conjunction with Practice E 1255 and MIL-STD-453. It permits the use of and gives guidance on the implementation of radioscopic examination for materials, components, and assemblies, when specified in the contract documents. The radioscopic requirements described herein allow the use of radioscopy for new applications as well as to replace radiography when inspection coverage, greater throughput, or improved inspection economics can be obtained, provided a satisfactory level of image quality can be demonstrated.

A1.1.2 *Application* — This annex provides guidelines for a written practice as required in 3.2 and 5.2.1 of Practice E 1255. Should the requirements in this annex conflict with any other requirements of Practice E 1255, then Annex A1 takes precedence. The requirements of this annex are intended to control the quality of the radioscopic examination and not to specify the accept/reject criteria for the test object. Accept/reject criteria are provided in other contract documents.

A1.2 Referenced Documents

A1.2.1 In addition to those documents referenced in Practice E 1255, the following standards are applicable to the extent specified herein.

A1.2.2 *ASTM Standards:*

E 1411 Practice for Qualification of Radiographic Systems
E 1453 Guide for Storage of Media That Contains Analog or Digital Radiographic Data

A1.2.3 *Military Standards:*
MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification
MIL-STD-453 Inspection, Radiographic
DOD-STD-2167 Defense System Software Development

A1.2.4 *American Welding Society Standard:*
ANSI/AWS 3.0 Welding Terms and Definitions

A1.2.5 *Government Standards* — Unless otherwise stated, the issues of these documents are those listed in the Defense Index of Specifications and Standards (DODISS) and supplement thereto, cited in the contract document.

A1.2.6 *Order of Preference* — In the event of conflict between the text of this document and the references listed in A1.2.2, this document shall take precedence. However, nothing in this document shall supersede applicable laws and regulations unless a specific exemption has been obtained from the cognizant authorities.

A1.3 Terminology

A1.3.1 *component* — the test part or parts described, assembled, or processed to the extent specified by the drawing.

A1.3.2 *contracting agency* — a prime contractor, subcontractor, or government agency that procures radioscopic examination services.

A1.3.3 *contract documents* — the procuring contract and all drawings, specifications, standards, and other information included with or referred to by the procuring contract.

A1.3.4 *mandatory radioscopic examination* — those radioscopic examinations which are a part of the required radiographic examinations specified in the contract documents.

A1.3.5 *NDT facility* — the organization that is responsible for the providing of nondestructive examination services.

A1.3.6 *optional radioscopic examination* — those radioscopic examinations which are conducted for process verification or information only and are not a part of the required radiographic examination specified in the contract documents.

A1.3.7 *prime contractor* — a contractor having responsibility for the design control and delivery to the department of defense for system/equipment such as aircraft, engines, ships, tanks, vehicles, guns and missiles, ground communications and electronic systems, ground support, and test equipment.

A1.3.8 *test object* — the material, component or assembly that is the subject of the radioscopic examination.

A1.3.9 *written procedure* — in radioscopy, a series of steps that are to be followed in a regular definite order. The radioscopic system operator follows the written procedure to consistently obtain the desired results and image quality level when performing radioscopic examination. The development of a radioscopic technique usually precedes the preparation of a written procedure.

A1.3.10 Other definitions not given herein shall be as specified in Terminology E 1316.

A1.4 General Requirements

A1.4.1 *Equipment Qualification* — Radioscopic system qualification shall be in accordance with Practice E 1411 and can best be evaluated with IQIs similar to the flaw type being investigated. A common IQI is described in MIL-STD-453.

A1.4.2 *Personnel Qualification* — Radioscopic personnel shall be qualified and certified in accordance with the general requirements of MIL-STD-410, until specific requirements for radioscopy are included. Radioscopic system qualification, the development of radioscopic examination test techniques, scan plans, and the overall implementation of radioscopic examination in accordance with this annex, shall be under the control and supervision of a qualified MIL-STD-410 Level III with additional radioscopy training and experience or in conjunction with an individual having the necessary training and experience in radioscopic examination.

A1.4.3 *Safety* — The performance or radioscopic examination shall present no hazards to the safety of personnel or property. Applicable Federal, state, and local radiation safety codes shall be adhered to. All radioscopic procedures shall be performed in a safe manner, such that personnel in that area are not exposed to any radiation dosage and shall in no case exceed Federal, state, and local limits.

A1.4.4 *Archival Recording of Mandatory Radioscopic Examination* — When required by contractual agreement, the radioscopic examination record shall contain the results of mandatory radioscopic examina-

tions. The radioscopic examination record shall be suitably archived for a period of time not less than five years from the examination date or as may otherwise be required in the contract documents. Efficient radioscopic examination record recall shall be available at any time over the record retention period. The radioscopic examination record shall be traceable to the test object (by serial number or other means) or to the batch or lot number, if tested in groups. Mandatory radioscopic examinations shall be specified in the contract documents. The optional radioscopic examinations are not specified in the contract documents.

A1.4.4.1 *Radioscopic Examination Record* — The recorded radioscopic examination record for mandatory examinations shall include the written results of the radioscopic examination and the radioscopic image, if an image is utilized in the accept/reject decision-making process. The recorded radioscopic image shall be provided with such additional information as may be required to allow the subsequent off-line review of the radioscopic examination results and, if necessary, the repeating of the radioscopic examination.

A1.4.4.2 *Image Recording Media* — The radioscopic image shall be recorded on a media that is appropriate to the radioscopic examination requirement. The recorded image shall reference the examination zones in such a way that the reviewer can confirm that all zones have been covered. The recorded radioscopic image shall provide an image quality at least equal to that for which the radioscopic system is qualified. The recording media shall be capable of maintaining the required image quality for the required record storage period or not less than five years from the recording date. The radioscopic image record shall be maintained in an operable condition for the duration of the record storage period, measured from the date when the last radioscopic image was recorded.

A1.4.4.3 *Recording Media Storage Conditions* — Media storage and handling shall be in accordance with Guide E 1453.

A1.4.5 *Image Quality Indicators* — Image quality indicators must be chosen with care to demonstrate the radioscopic system's ability to detect discontinuities or other features that are of interest. MIL-STD-453, Practice E 1025 plaque-type, and Practice E 747 wire-type IQIs and calibration blocks with real or simulated defects, to match the application, are all acceptable unless a particular IQI is specified in the contract documents. The selected IQI or calibration block shall be detailed in the written procedure. An IQI or calibration block may not be required for the following radioscopic examinations:

A1.4.5.1 When conducting radioscopy to check for adequate defect removal or grind-out, the final acceptance radioscopic examination shall include an IQI;

A1.4.5.2 Examinations to show material details or contrast between two or more dissimilar materials, in component parts or assemblies, including honeycomb areas for the detection of fabrication irregularities or the presence or absence of material;

A1.4.5.3 Examinations of electronic components for contamination, loose or missing elements, solder balls, broken or misplaced wires or connectors, and potted assemblies for broken internal components or missing potting compound;

A1.4.5.4 Optional radioscopic examinations; and

A1.4.5.5 Where the use of an IQI is impractical or ineffective, an alternate method may be used, subject to the approval of the contracting agency.

A1.4.6 *Classification of Test Object Zones for Radioscopy* — The classification of test objects into zones for various accept/reject criteria shall be determined from the contract documents.

A1.5 Detailed Requirements

A1.5.1 *Application Qualification:*

A1.5.1.1 *New Applications* — Radioscopy may be used where appropriate for new examination requirements, provided the required performance, including image quality, can be met.

A1.5.1.2 *Replacement of Existing Radiographic Applications* — When agreed to by the contracting officer, radioscopy may be used to replace or augment existing radiographic applications, provided that the radioscopic results correlate favorably with the results obtained with X-ray film produced in accordance with MIL-STD-453. Favorable correlation means that the radioscopic and film images show similar sensitivity to test object features that are of interest.

A1.5.2 *Written Procedure* — It shall be the responsibility of the NDE facility to develop a written radioscopic examination procedure to ensure the effective and repeatable radioscopic examination of the test object. A test object scan plan for dynamic radioscopic systems, meeting the requirements of Practice E 1255 (see 5.2.1.2), shall be included in the written procedure. Those portions of the contract document that specify

and detail radioscopic examination shall become an appendix to the written procedure. The written procedure must be approved by the Level III of the NDE facility. Where required, the written procedure shall be approved by the contracting agency prior to use. The written procedure shall include as a minimum the following information:

A1.5.2.1 A drawing, sketch, or photograph of the component that shows the radiation beam axis, positions(s) of the detector, and applicable IQI for each and all variations of the test object orientation and beam energy. This requirement may be expressed in coordinates for automated systems having calibrated manipulation systems;

A1.5.2.2 A physical description of the test object, including size, thickness, weight, and composition;

A1.5.2.3 Classification of the test object into zones for radioscopy;

A1.5.2.4 Test part masking, if used, for each required view;

A1.5.2.5 Added radiation source collimation, expressed in terms of the radiation field dimensions at the test object source side, for each required view;

A1.5.2.6 Detector field of view for each required view;

A1.5.2.7 Detector diaphragm settings, expressed in terms of field of view at the detector, for each required view;

A1.5.2.8 The allowable range of radiation energy and beam current or source intensity and the focal spot or source size for each required view;

A1.5.2.9 Added beam filtration, if used, for each required view;

A1.5.2.10 The inspection geometry and coverage for each required view;

A1.5.2.11 Type of IQI or calibration block used and the required quality level;

A1.5.2.12 All hardware and software settings that can be changed by the operator to affect the outcome of the radioscopic examination. Such settings include, but are not limited to, video camera and display settings and image processor variables; and

A.1.5.2.13 The recording media and storage image format for mandatory radioscopic image storage.

A1.5.3 *Test Object Examination* — The number of test objects to be examined and the coverage required for each test object shall be specified in the contract documents. If not specified, all test objects shall receive 100% radioscopic coverage as detailed in the written procedure.

A1.5.4 *Image Quality* — Unless otherwise specified in the contract documents, the required image quality level is 2-2*T*. Image quality assessment shall be performed using the same system parameters as in the inspection and as documented in the written procedure.

A1.5.4.1 The IQI may be placed on the test object or on a mounting block, at or near the test object location, following the requirements of MIL-STD-453. In the case of small radioscopic fields of view or other situations where it is not practical to place the IQI in the field of view with the test object and maintain it normal to the X-ray beam, the IQI may be imaged immediately before and after the test object examination. Batch quantities of similar parts need not have IQI images made between each part, at the discretion of the Level III. The radioscopic examination results shall be invalid, if the before and after IQI images fail to demonstrate the required sensitivity. The before and after IQI images shall be considered a part of the test object image for radioscopic image interpretation and archiving purposes.

A1.5.4.2 With written permission from the contracting agency, other IQIs or a calibration block with natural or artificial flaws may be used instead of the specified IQI.

A1.5.5 *Radioscopic System Qualification* — The radioscopic system, including mandatory radioscopic image archiving devices, shall be qualified to the image quality level required for test object examination. Radioscopic system initial qualification shall be in accordance with Practice E 1411.

A1.5.6 *Radioscopic System Requalification* — The radioscopic system, including mandatory image archiving devices, shall be periodically requalified at intervals frequent enough to ensure the required level of radioscopic system performance. Each requalification shall be carried out in accordance with Practice E 1411.

A1.5.7 *Inspection Image Control* — The radioscopic system shall be checked for performance before each day's production usage using the method and devices that were initially used to qualify the written procedure. A log shall be maintained to document any changes in system performance requiring changes in

operating parameters and listing all equipment maintenance. System requalification shall be required whenever image quality requirements can no longer be met.

A1.5.8 *Repair of Radioscopic System* — Repair or replacement of key radioscopic system components including, but not limited to, the radiation source, image forming, image transmission, image processing, and image display subsystems shall be cause for system requalification. In no case shall the interval between qualification tests exceed one year. The qualification statement shall be posted on the radioscopic system. The results of the qualification tests shall be maintained in the radioscopic system equipment file until the completion of the next qualification procedure or the expiration of the archival image retention period, whichever is longer.

A1.5.9 *Image Interpretation:*

A1.5.9.1 *Static Imaging* — Radioscopic system qualification in accordance with Practice E 1411 applies to static imaging conditions only where the test part is stationary with respect to the X-ray beam. Therefore, all performance measurements are based upon static image quality. All mandatory radioscopic examination accept/reject decisions shall be based upon the assessment of static images.

A1.5.9.2 *Dynamic Imaging* — Dynamic or in-motion imaging may be used to gain useful information about the test object. However, unless dynamic imaging is specified, the final assessment of image formation for mandatory radioscopic examinations shall be made in the static mode. When the contracting agency specifies dynamic inspection, all aspects of the procedure must be approved by MIL-STD-410 Level III personnel. For dynamic inspection, the image quality shall be measured under the same procedure as the inspection.

A1.5.10 *Feature Size Determination* — Where feature measurement from the radioscopic image is required, the written procedure shall include methodology for determining and maintaining the accuracy of the selected measurement method.

A1.5.10.1 *Feature Measurement by Test Object Displacement* — For those radioscopic systems with calibrated manipulation systems, the more accurate, and therefore preferred, method of measurement is to manipulate the extremities of the feature to be measured to a common central reference point within the radioscopic image field of view. The dimension may then be read from the manipulation system position display.

A1.5.10.2 *Feature Measurement by Comparison* — A second method involves comparing the test object feature with a known, observable dimension which must be wholly within the radioscopic field of view. Many digital image processors facilitate this type of measurement by counting pixels over the feature length. The pixel number is often converted to engineering units by comparison with a known length. However, the orientation and position along the X-ray beam (magnification) of both the feature and the calibrating reference length affect the accuracy of such measurements.

A1.5.11 *Gray Scale Range* — The gray scale range required to meet initial qualification contrast sensitivity requirements for image quality shall be recorded and monitored. For systems using human image assessment, it is particularly important that the gray scale range and the number of gray scale steps be closely matched to the response of the human eye. The written procedure shall include a means for monitoring the required gray scale range using a contrast sensitivity gage, step wedge, or similar device made of the test object or IQI material.

A1.5.12 *Timing of Radioscopic Examination* — Radioscopic examination shall be performed at the time of manufacturing, assembly, or rework as required by the contract documents.

A1.5.13 *Identification* — A means shall be provided for the positive identification of the test object to the archival radioscopic inspection record. Archived radioscopic images shall be annotated to agree with the test object identification.

A1.5.14 *Locating the Radioscopic Examination Areas* — Whenever more than one image is required for a weldment or other test object, location markers shall be placed on the test object in order that the orientation of the test object and the location of test object features relative to the radioscopic field of view may be established. This requirement shall not apply to automated systems having programmed radioscopic examination sequences where coverage has been proven during the development of the scan plan. Also, this requirement does not apply to the radioscopic examination of simple or small shapes where the test part orientation is obvious and coverage is not in question.

A1.5.15 *Surface Preparation* — Test objects may be inspected without surface preparation, except when required to remove surface conditions that may interfere with proper interpretation of the radioscopic image or that may create a safety hazard.

A1.5.16 *Detailed Data* — The provider of radioscopic examination services shall keep the written procedure, qualification documentation, and the signed inspection reports or tabulated results, or both, for five years from the radioscopic examination date, unless otherwise specified in the contract documents. For software-based automated radioscopic systems using custom software, a copy of the source code and the related inspection parameters shall also be maintained on file for a like period of time. This requirement shall not apply to standard commercially available software packages or to traceable software documentation which complies with DOD-STD-2167 where a separate copy of the software is maintained.

A1.5.17 *Radioscopic Reexamination of Repairs* — When repair has been performed as the result of radioscopic examination, the repaired areas shall be reexamined using the same radioscopic technique to evaluate the effectiveness of the repair. Each repaired area shall be identified with R1, R2, R3, and so forth, to indicate the number of times repair was performed.

A1.5.18 *Retention of Radioscopic Examination Records* — Mandatory radioscopic examination records and associated radioscopic images shall be stored in a proper repository at the contractor's plant for five years from the date from which they were made. Special instructions, such as storage for other periods of time, making backup copies, copying the records to other media, or having the records destroyed shall be specified in the contract documents.

A1.5.19 *Rejection of Test Objects* — Test objects containing defects exceeding the permissible limits specified in the contract documents shall be separated from acceptable material, appropriately identified as discrepant, and submitted for material review when required by the contract documents.

A1.5.20 *Reexamination* — When there is a reasonable doubt as to the ability to interpret the radioscopic results because of improper execution or equipment malfunction, the test object shall be reexamined using the correct procedure. If the problem is not resolved by reexamination, the procedure shall be reviewed by the Level III of the NDE facility and adjusted, if necessary. Reference exposures may be made using radiography if necessary. If the reexamination was caused by equipment malfunction, the equipment may not be returned to service until the malfunction is repaired and the equipment is requalified to the current qualification requirements in accordance with Practice E 1411.

A1.5.21 *Test Object Marking* — The marking of test objects shall be as specified in MIL-STD-453.

A1.6 Notes

A1.6.1 This section contains information of a general or explanatory nature and is not mandatory.

A1.6.1.1 Caution — Active electronic components and some materials, such as tetrafluoroethylene, are subject to radiation damage if exposed to large doses of radiation. While normal radioscopic examinations should cause no problem, extended periods of radiation exposure should be avoided.

A1.6.1.2 *Human Factors* — The success of radioscopic examinations which involve human image interpretation are, like radiography, subject to human factors. Careful attention should be given to the human environment where image interpretation takes place, to make it as conducive to correct, consistent image interpretation as possible. Measures should also be implemented to ensure that fatigue does not interfere with correct and consistent radioscopic image interpretation.

A1.6.1.3 *Use of IQI(s)* — As with radiography, the achievement of the required IQI sensitivity does not guarantee the ability to find all defects down to the minimum defect size. This is due to the fact that many defects, especially those of a planar nature, are very orientation sensitive. When using dynamic radioscopic systems, care must be taken to see that the scan plan includes sufficient manipulations to maximize the possibility that orientation-sensitive defects will be found. It is for this reason that the use of calibration blocks with real or simulated defects may more accurately characterize the ability of the radioscopic system to find orientation-sensitive defects when using dynamic radioscopic systems.

A1.6.1.4 *Use of Image-Processing Techniques* — Care should be exercised in applying digital image–processing techniques to evaluate the overall effect upon image quality. For example, contrast enhancement techniques may emphasize contrast in one brightness range, while decreasing contrast in other brightness ranges. Some spatial filters have directional aspects, whereby features in one direction are emphasized while those in the orthogonal direction are deemphasized. Such cautions are intended to cause the careful evaluation of digital image–processing techniques and not to discourage their use.

A1.6.1.5 *Feature Size Determination* — As with radiography, great care must be exercised in trying to assess test part feature dimensions from a two-dimensional projected view.

A2. NONGOVERNMENT CONTRACT SUPPLEMENTAL REQUIREMENTS

A2.1 Scope

A2.1.1 *Purpose* — This annex is to be used in conjunction with Practice E 1255. This annex includes application-specific details as may be agreed upon by the purchaser and the supplier of radioscopic examination services.

A2.1.2 *Application* — This document satisfies the requirements of 3.2 and 5.2.1 of Practice E 1255. Should this annex conflict with any other requirements of Practice E 1255, this annex shall prevail. The requirements of this annex are intended to control the quality of the radioscopic examination and not to specify the accept/reject criteria for the test object. Accept/reject criteria are provided in other contract documents.

A2.2 Terminology

A2.2.1 *component* — the test part or parts described, assembled, or processed to the extent specified by the drawing.

A2.2.2 *contract documents* — the procuring contract and all drawings, specifications, standards, and other information included with or referred to by the procuring contract.

A2.2.3 *contractor* — a contractor having first level responsibility for the design, manufacture, and delivery of an end item. When radioscopic examination is required, the contractor is the user of radioscopic examination services.

A2.2.4 *mandatory radioscopic examination* — those radioscopic examinations which are a part of the required radiographic examinations specified in the contract documents.

A2.2.5 *NDE facility* — the organization that is responsible for providing nondestructive examination services.

A2.2.6 *optional radioscopic examination* — those radioscopic examinations that are conducted for process verification or information only and are not a part of the required radiographic examinations specified in the contract documents.

A2.2.7 *provider of radioscopic services* — a contractor, subcontractor, or other entity that provides radioscopic examination services.

A2.2.8 *test object* — the material, component, or assembly that is the subject of the radioscopic examination.

A2.2.9 *user of radioscopic services* — a contractor, subcontractor, or other entity that procures radioscopic examination services. The provider and user of radioscopic examination services may be a part of the same organization or different organizations.

A2.2.10 *written procedure* — in radioscopy, a series of steps that are to be followed in a regular definite order. The radioscopic system operator follows the written procedure to consistently obtain the desired results and image quality level when performing radioscopic examination. The development of a radioscopic technique usually precedes the preparation of a written procedure.

A2.2.11 Other definitions not given herein shall be as specified in Terminology E 1316.

A2.3 General Requirements

A2.3.1 *Equipment Qualification* — Radioscopic system qualification shall be in accordance with Practice E 1411, using Practice E 747 and Practice E 1025 image quality indicators or a calibration block containing actual or simulated defects.

A2.3.2 *Personnel Qualification* — Radioscopic personnel shall be qualified and certified in accordance with the requirements of SNT-TC-1A or ANSI/ASNT CP-189. Radioscopic system qualification, the development of radioscopic examination test techniques, scan plans, and the overall implementation of radioscopic examination in accordance with this annex shall be under the control and supervision of a qualified Level III with additional radioscopy training and experience, or in conjunction with an individual having the necessary training and experience in radioscopic examination. Operation of the radioscopic system, including interpretation of the radioscopic image, shall be made by qualified Level II personnel.

A2.3.3 *Safety* — The performance of radioscopic examination shall present no hazards to the safety of personnel or property. Applicable Federal, state, and local radiation safety codes shall be adhered to. All radioscopic procedures shall be performed so that per-

sonnel shall receive the minimum dosage and in no case exceed Federal, state, and local limits.

A2.3.4 *Archival Recording of Mandatory Radioscopic Examinations* — The radioscopic examination record shall contain the results for mandatory radioscopic examinations. The radioscopic examination record shall be suitably archived for a period of one year after the date of radioscopic examination or for a longer time if specified in the contract documents. Efficient radioscopic examination record recall shall be available at any time over the record retention period. The radioscopic examination record shall be traceable to the test object by serial number or other means. This requirement will not apply to optional radioscopic examinations that are not specified in the contract documents.

A2.3.4.1 *Radioscopic Examination Record* — The recorded radioscopic examination record for mandatory examinations shall include the written results of the radioscopic examination and the radioscopic image, if an image is utilized in the accept/reject decision-making process. The recorded radioscopic image shall be provided with such additional information as may be required to allow the subsequent off-line review of the radioscopic examination results and, if necessary, the repeating of the radioscopic examination.

A2.3.4.2 *Image Recording Media* — The radioscopic image shall be recorded on a media that is appropriate to the radioscopic examination requirement. The recorded image shall reference the examination zones in such a way that the reviewer can confirm that all zones have been covered. The recorded radioscopic image shall provide an image quality at least equal to that for which the radioscopic system is qualified. The recording media shall be capable of maintaining the required image quality for the required record storage period or not less than five years from the recording date. The recorded radioscopic image playback shall be maintained in an operable condition for the duration of the record storage period measured from the date when the last radioscopic image was recorded.

A2.3.4.3 *Recording Media Storage Conditions* — Media storage and handling shall be in accordance with Guide E 1453.

A2.3.4.4 *Other Recording* — Where the recording of the radioscopic examination record is not in fulfillment of mandatory archival recording requirements, other recording methods and media may be used.

A2.3.5 *Image Quality Indicators* — An IQI must be chosen with care to demonstrate the radioscopic system's ability to detect discontinuities, or other features of interest. Practice E 1025 plaque-type and Practice E 747 wire-type IQIs and calibration blocks with real or simulated defects that match the application are all acceptable unless a specific IQI is specified in the contract documents. The selected IQI or calibration block shall be detailed in the written procedure. An IQI or calibration block may not be required for the following radioscopic examinations:

A2.3.5.1 Examining assemblies for debris or foreign objects.

A2.3.5.2 Conducting radioscopy for adequate defect removal or grind-out. However, the final acceptance radioscopic examination shall include an IQI.

A2.3.5.3 Examinations to show material details or contrast between two or more dissimilar materials in component parts or assemblies including honeycomb areas for the detection of fabrication irregularities or the presence or absence of material.

A2.3.5.4 Examining electronic components for contamination, loose or missing elements, solder balls, broken or misplaced wires, or connectors and potted assemblies for broken internal components or missing potting compound.

A2.3.5.5 Optional radioscopic examinations.

A2.3.5.6 Where the use of an IQI is impractical or ineffective, an alternate method may be used, subject to the approval of the contracting agency.

A2.3.6 *Classification of Test Object Zones for Radioscopy* — The classification of test objects into zones for various accept/reject criteria shall be determined from the contract documents. In cases where no accept/reject criteria are specified, the Level III of the NDE facility shall document those anomalies considered critical and indicate in writing that no formal accept/reject criteria were provided.

A2.4 Detailed Requirements

A2.4.1 *Application Qualification* — Radioscopy may be used where appropriate for new as well as existing radiographic examination requirements provided that the required performance, including image quality, can be met. Where radioscopy is used to replace or augment existing radiographic applications, the radioscopic results should correlate favorably with the results obtained with radiographic film-produced techniques.

Favorable correlation means that the radioscopic and film images show similar sensitivity to test object features which are of interest.

A2.4.2 *Written Procedure* — It shall be the responsibility of the NDE facility to develop a written radioscopic examination procedure to ensure the effective and repeatable radioscopic examination of the test object. When a dynamic radioscopic system is used, a test object scan plan meeting the requirements of Practice E 1255 (see 5.2.1.2) shall be included in the written procedure. Those portions of the contract document that specify and detail radioscopic examination shall become an appendix to the written procedure. The written procedure must be written or approved by the Level III of the NDE facility. Where required, the written procedure shall be approved by the contracting agency prior to use. The written procedure shall include as a minimum the following information:

A2.4.2.1 A drawing, sketch, or photograph of the component that shows the radiation beam axis, position(s) of the detector and applicable IQI for each and all variations of the test object orientation, and beam energy. This requirement may be expressed in coordinates for automated systems having calibrated manipulation systems.

A2.4.2.2 A physical description of the test object including size, weight, and composition.

A2.4.2.3 Classification of test object into zones for radioscopy.

A2.4.2.4 Test part masking, if used, for each required view.

A2.4.2.5 Added radiation source collimation, expressed in terms of the radiation field dimensions at the test object source side for each required view.

A2.4.2.6 Detector field of view for each required view.

A2.4.2.7 Detector diaphragm settings, expressed in terms of field of view at the detector for each required view.

A2.4.2.8 The allowable range of radiation energy and beam current or source intensity and the focal spot or source size for each required view.

A2.4.2.9 Added beam filtration, if used, for each required view.

A2.4.2.10 The inspection geometry and coverage for each required view.

A2.4.2.11 Type of IQI or calibration block used and the required quality level.

A2.4.2.12 All hardware and software settings which can be changed by the operator to affect the outcome of the radioscopic examination. Such settings include, but are not limited to, video camera, display settings, and image processor variables.

A2.4.2.13 The recording media and stored image format for mandatory radioscopic image storage.

A2.4.3 *Test Object Examination* — The number of test objects to be examined and the coverage required for each test object shall be specified in the contract documents. If not specified, all test objects shall receive 100% radioscopic coverage as detailed in the written procedure.

A2.4.4 *Image Quality* — Unless otherwise specified in the contract documents, the required image quality level is 2-2*T*. Image quality assessment shall be made in the same mode as that used for the inspection.

A2.4.4.1 The IQI may be placed on the test object or on a mounting block at or near the test object location. In the case of small radioscopic fields of view or other situations where it is not practical to place the IQI in the field of view with the test object and maintain it normal to the X-ray beam, the IQI may be imaged immediately before and after the test object examination or batch of test objects if they are similar. The radioscopic examination results shall be invalid if the before and after IQI images fail to demonstrate the required sensitivity. Before and after IQI images shall be considered a part of the test object image for radioscopic image interpretation and archiving purposes.

A2.4.5 *Radioscopic System Qualification* — The radioscopic system including mandatory radioscopic image archiving devices shall be qualified to the image quality level required for test object examination. Radioscopic system initial qualification and periodic requalification shall be in accordance with Practice E 1411.

A2.4.6 *Radioscopic System Requalification* — The radioscopic system, including mandatory image archiving devices, shall be periodically requalified at intervals frequent enough to ensure the required level of radioscopic system performance.

A2.4.7 *Inspection Image Control* — The radioscopic system shall be checked for performance before each day's production usage using the method and devices that were initially used to qualify the written procedure. A log shall be maintained to document any

changes in system performance requiring changes in operating parameters and listing all equipment maintenance. System requalification shall be required whenever image quality requirements can no longer be met.

A2.4.8 *Repair of Radioscopic System* — Repair or replacement of key radioscopic system components including but not limited to the radiation source, image forming, image transmission, image processing, and image display subsystems shall be cause for system requalification. In no case shall the interval between qualification tests exceed one year. The qualification statement shall be posted on the radioscopic system. The results of the qualification tests shall be maintained in the radioscopic system equipment file at least until completion of the next qualification procedure or the expiration of the archival image retention period, whichever is longer.

A2.4.9 *Image Interpretation:*

A2.4.9.1 *Static Imaging* — Radioscopic system qualification in accordance with Practice E 1411 applies to static imaging conditions, only where the test part is stationary with respect to the X-ray beam. Therefore, all performance measurements are based upon static image quality. All mandatory radioscopic examination accept/reject decisions shall be based upon the assessment of static images.

A2.4.9.2 *Dynamic Imaging* — Dynamic or in-motion imaging may be used to gain useful information about the test object. However, the final assessment of image information for mandatory radioscopic examinations shall be made in the static mode.

A2.4.10 *Feature Size Determination* — Where feature measurement from the radioscopic image is required, the written procedure shall include methodology for determining and maintaining the accuracy of the selected measurement method.

A2.4.10.1 *Feature Measurement by Test Object Displacement* — For those radioscopic systems with calibrated manipulation systems, the more accurate and therefore preferred method of measurement is to manipulate the extremities of the feature to be measured to a common central reference point within the radioscopic image field of view. The dimension may then be read from the manipulation system position display.

A2.4.10.2 *Feature Measurement by Comparison* — A second method involves comparing the test object feature with a known, observable dimension which must be wholly within the radioscopic field of view. Many digital image processors facilitate this type of measurement by counting pixels over the feature length. The pixel number is often converted to engineering units by comparison with a known length. However, the orientation and position along the X-ray beam (magnification) of both the feature and the calibrating reference length affect the accuracy of such measurements.

A2.4.11 *Gray Scale Range* — The gray scale range required to meet initial qualification contrast sensitivity requirements for image quality shall be recorded and monitored. For systems using human image assessment, it is particularly important that the gray scale range and the number of gray scale steps be closely matched to the response of the human eye. The written procedure shall include a means for monitoring the required gray scale range using a contrast sensitivity gage, step wedge, or similar device made of the test object or IQI material.

A2.4.12 *Timing of Radioscopic Examination* — Radioscopic examination shall be performed at the time of manufacturing, assembly, or rework as required by the contract documents.

A2.4.13 *Identification* — A means shall be provided for the positive identification of the test object to the archival radioscopic inspection record. Archived radioscopic images shall be annotated to agree with the test object identification.

A2.4.14 *Locating the Radioscopic Examination Areas* — Whenever more than one image is required for a weldment or other test object, location markers shall be placed on the test object in order that the orientation of the test object and the location of test object features relative to the radioscopic field of view may be established. This requirement shall not apply to automated systems having programmed radioscopic examination sequences where coverage has been proven during the development of the scan plan. Also, this requirement does not apply to the radioscopic examination of simple or small shapes where the test part orientation is obvious and coverage is not in question.

A2.4.15 *Surface Preparation* — Test objects may be inspected without surface preparation except as may be required to remove surface conditions which may interfere with proper interpretation of the radioscopic image or create a safety hazard.

A2.4.16 *Detailed Data* — The provider of radioscopic examination services shall keep the written procedure, qualification documentation, and the signed inspection reports or tabulated results for five years from the

radioscopic examination date unless otherwise specified in the contract documents. For software-based automated radioscopic systems using custom software, a copy of the source code and the related inspection parameters shall also be maintained on file for a like period of time. This requirement shall not apply to standard commercially available software packages where a separate copy of the software is maintained.

A2.4.17 *Radioscopic Reexamination of Repairs* — When repair has been performed as the result of radioscopic examination, the repaired areas shall be reexamined using the same radioscopic technique to evaluate the effectiveness of the repair. Each repaired area shall be identified with R1, R2, R3, and so forth, to indicate the number of times repair was performed.

A2.4.18 *Retention of Radioscopic Examination Record* — Mandatory radioscopic examination records and associated radioscopic images shall be stored in a proper repository at the contractor's plant for one year from the date from which they were made. Special instructions, such as storage for other periods of time, making backup copies, copying the records to other media, or having the records destroyed shall be specified in the contract documents.

A2.4.19 *Rejection of Test Objects* — Test objects containing defects exceeding the permissible limits specified in the contract documents shall be separated from acceptable material, appropriately identified as discrepant, and submitted for material review when required by the contract documents.

A2.4.20 *Reexamination* — Where there is an inability to interpret the radioscopic results because of improper execution or equipment malfunction, the test object shall be reexamined using the correct procedure. If the problem is not resolved by reexamination, the procedure shall be reviewed by the Level III of the NDE facility and adjusted, if necessary. Reference exposures may be made using radiography if necessary. If the reexamination was caused by equipment malfunction, the equipment may not be returned to service until the malfunction is repaired and the equipment is requalified to the current qualification requirements in accordance with Practice E 1411.

A2.4.21 *Test Object Disposition* — Test objects that have undergone radioscopic examination shall be marked or physically separated in such a manner so as to minimize the possibility of rejected or questionable test objects being confused with acceptable ones.

A2.5 Notes

A2.5.1 This section contains information of a general or explanatory nature and is not mandatory.

A2.5.1.1 Caution — Active electronic components and some materials, such as tetrafluoroethylene, are subject to radiation damage if exposed to large doses of radiation. While normal radioscopic examinations should cause no problem, extended periods of radiation exposure should be avoided.

A2.5.1.2 *Human Factors* — The success of radioscopic examinations which involve human image interpretation are, like radiography, subject to human factors. Careful attention should be given to the human environment where image interpretation takes place, to make it as conducive to correct, consistent image interpretation as possible. Measures should also be implemented to ensure that fatigue does not interfere with correct and consistent radioscopic image interpretation.

A2.5.1.3 *Use of IQI* — As with radiography, the achievement of the required IQI sensitivity does not guarantee the ability to find all defects down to the minimum defect size. This is due to the fact that many defects, especially those of a planar nature, are very orientation sensitive. When a dynamic radioscopic system is used, care must be taken to see that the scan plan includes sufficient manipulation to maximize the possibility that orientation-sensitive defects will be found. It is for this reason that the use of calibration blocks with real or simulated defects may more accurately characterize the ability of the radioscopic system to find orientation-sensitive defects.

A2.5.1.4 *Use of Image-Processing Techniques* — Care should be exercised in applying digital image–processing techniques to evaluate the overall effect upon image quality. For example, contrast enhancement techniques may emphasize contrast in one brightness range while decreasing contrast in other brightness ranges. Some spatial filters have directional aspects whereby features in one direction are emphasized while those in the orthogonal direction are deemphasized. Such cautions are intended to cause the careful evaluation of digital image–processing techniques and not to discourage their use.

A2.5.1.5 *Feature Size Determination* — As with radiography, great care must be exercised in trying to assess test part feature dimensions from a two-dimensional projected view.

STANDARD TEST METHOD FOR RADIOSCOPIC EXAMINATION OF WELDMENTS

SE-1416

(Identical with ASTM Specification E 1416-96)

1. Scope

1.1 This test method covers a uniform procedure for radioscopic examination of weldments. Requirements expressed in this test method are intended to control the quality of the radioscopic images and are not intended for controlling acceptability or quality of welds.

1.2 This test method applies only to the use of equipment for radioscopic examination in which the image is finally presented on a television monitor for operator evaluation. The examination may be recorded for later review. It does not apply to fully automated systems where evaluation is automatically performed by computer.

1.3 The radioscopic extent, the quality level, and the acceptance criteria to be applied shall be specified in the contract, purchase order, product specification, or drawings.

1.4 This test method can be used for the detection of discontinuities. This test method also facilitates the examination of a weld from several directions, such as perpendicular to the weld surface and along both weld bevel angles. The radioscopic techniques described in this test method provide adequate assurance for defect detectability; however, it is recognized that, for special applications, specific techniques using more stringent requirements may be needed to provide additional detection capability. The use of specific radioscopic techniques shall be agreed upon between purchaser and supplier.

1.5 The values stated in inch-pound units are to be regarded as the standard. The SI units given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements are given in Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*

E 94 Guide for Radiographic Testing
E 543 Practice for Agencies Performing Nondestructive Testing
E 747 Practice for Design, Manufacture, and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology
E 1000 Guide for Radioscopy
E 1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology
E 1255 Practice for Radioscopy
E 1316 Terminology for Nondestructive Examinations

2.2 *ASNT Standards:*

ASNT Recommended Practice No. SNT-TC-1A Personnel Qualification and Certification in Nondestructive Testing
ANSI/ASNT CP-189-ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *Military Standard:*

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification (Eddy Current, Liquid Penetrant, Magnetic Particle, Radiographic, Ultrasonic)

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions of terms applicable to this test method may be found in Terminology E 1316.

4. Materials

4.1 *Recording Media* — Recording media for storage of images shall be in a format agreed by the purchaser and supplier. This may include either analog or digital media.

5. Apparatus

5.1 *Radiation Source (X-Ray or Gamma-Ray)* — Selection of the appropriate source is dependent upon variables regarding the weld being examined, such as material composition and thickness. The suitability of the source shall be demonstrated by attainment of the required image quality and compliance with all other requirements stipulated herein. Guidance on the selection of the radiation source may be found in Guide E 1000 and Practice E 1255.

5.2 *Manipulation System* — Selection of the appropriate manipulation system (where applicable) is dependent upon variables such as the size and orientation of the object being examined and the range of motions, speed of manipulation, and smoothness of motion. The suitability of the manipulation system shall be demonstrated by attainment of the required image quality and compliance with all other requirements stipulated herein. Guidance on the selection of the manipulation system may be found in Practice E 1255.

5.3 *Imaging System* — Selection of the appropriate imaging system is dependent upon variables such as the size of the object being examined and the energy and intensity of the radiation used for the examination. The suitability of the imaging system shall be demonstrated by attainment of the required image quality and compliance with all other requirements stipulated herein. Guidance on the selection of an imaging system may be found in Guide E 1000 and Practice E 1255.

5.4 *Image Processing System* — Where agreed between purchaser and supplier, image processing systems may be used for noise reduction through image integration or averaging, contrast enhancement and other image processing operations.

5.5 *Collimation* — Selection of appropriate collimation is dependent upon the geometry of the object being examined. It is generally useful to select collimation to limit the primary radiation beam to the weld and the immediately adjacent base material in order to improve radioscopic image quality.

5.6 *Filters and Masking* — Filters and masking may be used to improve image quality from contrast reductions caused by low-energy scattered radiation. Guidance on the use of filters and masking can be found in Guide E 94.

5.7 *Image Quality Indicators (IQI)* — Unless otherwise specified by the applicable job order or contract, image quality indicators shall comply with the design and identification requirements specified in Practices E 747 or E 1025.

5.8 *Shims, Separate Blocks, or Like Sections* — Shims, separate blocks, or like sections made of the same or radioscopically similar materials (as defined in Practice E 1025) may be used to facilitate image quality indicator positioning as described in 9.10.3. The like section should be geometrically similar to the object being examined.

5.9 *Location and Identification Markers* — Lead numbers and letters should be used to designate the part number and location number. The size and thickness of the markers shall depend on the ability of the radioscopic technique to discern the markers on the images. As a general rule, markers from 0.06 to 0.12 in. (1.5 to 3 mm) thick will suffice for most low energy (less than 1 MeV) X-ray and iridium-192 radioscopy. For higher energy (greater than 1 MeV and cobalt-60) radioscopy, it may be necessary to use markers that are thicker [0.12 in. (3 mm) thick or more]. In cases where the system being used provides a display of object position within the image, this shall be acceptable as identification of object location.

6. Basis of Application

6.1 *Personnel Qualification* — NDT personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, MIL STD 410, or a similar document. The practice or standard used and its applicable revision shall be specified in the contractual agreement between the using parties.

6.2 *Qualification of Nondestructive Testing Agencies* — If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E 543. The applicable edition of Practice E 543 shall be specified in the contractual agreement.

6.3 *Time of Examination* — The time of examination shall be in accordance with 9.1 unless otherwise specified.

6.4 *Procedures and Techniques* — The procedures and techniques to be utilized shall be as described in this test method unless otherwise specified. Specific techniques may be specified in the contractual agreement.

6.5 *Extent of Examination* — The extent of examination shall be in accordance with 8.3 unless otherwise specified.

6.6 *Reporting Criteria/Acceptance Criteria* — Reporting criteria for the examination results shall be in accordance with Section 10 unless otherwise specified. Acceptance criteria shall be specified in the contractual agreement.

6.7 *Reexamination of Repaired/Reworked Items* — Reexamination of repaired/reworked items is not addressed in this test method and if required shall be specified in the contractual agreement.

7. Safety

7.1 Radioscopic procedures shall comply with applicable city, state, and federal safety regulations.

8. Requirements

8.1 *Procedure Requirement* — Unless otherwise specified by the applicable job order or contract, radioscopic examination shall be performed in accordance with a written procedure. Specific requirements regarding the preparation and approval of the written procedures shall be as agreed by purchaser and supplier. The production procedure shall address all applicable portions of this test method and shall be available for review during interpretation of the images. The written procedure shall include the following:

8.1.1 Material and thickness range to be examined,

8.1.2 Equipment to be used, including specifications of source parameters (such as tube voltage, current, focal spot size) and imaging equipment parameters (such as detector size, field of view, electronic magnification, camera black level, gain),

8.1.3 Examination geometry, including source-to-object distance, object-to-detector distance and orientation,

8.1.4 Image quality indicator designation and placement,

8.1.5 Test-object scan plan, indicating the range of motions and manipulation speeds through which the test object shall be manipulated in order to ensure satisfactory results (see description in 5.2.1.2 of Practice E 1255),

8.1.6 Image-processing parameters,

8.1.7 Image-display parameters, and

8.1.8 Image storage.

8.2 *Radioscopic Coverage* — Unless otherwise specified by purchaser and supplier agreement, the extent of radioscopic coverage shall include 100% of the volume of the weld and the adjacent base metal.

8.3 *Examination Speed* — For dynamic examination, the speed of object motion relative to the radiation source and detector shall be controlled to ensure that the required radioscopic quality level is achieved.

8.4 *Radioscopic Image Quality* — All images shall be free of marks or other blemishes that could mask or be confused with the image of any discontinuity in the area of interest. It may be possible to prevent blemishes from masking discontinuities or being confused with discontinuities by moving the object being examined relative to the imaging device. If any doubt exists as to the true nature of an indication exhibited in the image, the image shall be rejected and a new image of the area shall be made.

8.5 *Radioscopic Quality Level* — Radioscopic quality level shall be determined upon agreement between the purchaser and supplier and shall be specified in the applicable job order or contract. Radioscopic quality shall be specified in terms of equivalent penetrameter (IQI) sensitivity and shall be measured using image quality indicators conforming to Practices E 747 or E 1025.

8.6 *Acceptance Level* — Accept and reject levels shall be stipulated by the applicable contract, job order, drawing, or other purchaser and supplier agreement.

8.7 *Image-Viewing Facilities* — Viewing facilities shall provide subdued background lighting of an intensity that will not cause troublesome reflection, shadows, or glare on the image.

8.8 *Storage of Images* — When storage is required by the applicable job order or contract, the images should be stored in a format stipulated by the applicable contract, job order, drawing, or other purchaser and

supplier agreement. The image-storage duration and location shall be as agreed between purchaser and supplier.

9. Procedure

9.1 *Time of Examination* — Unless otherwise specified by the applicable job order or contract, perform radioscopy prior to heat treatment.

9.2 *Surface Preparation* — Unless otherwise agreed upon, remove the weld bead ripple or weld-surface irregularities on both the inside and outside (where accessible) by any suitable process so that the image of the irregularities cannot mask, or be confused with, the image of any discontinuity. Interpretation can be optimized if surface irregularities are removed such that the image of the irregularities is not discernible.

9.3 *Source to Detector Distance* — Unless otherwise specified in the applicable job order or contract, geometric unsharpness (U_g) shall not exceed the following:

Material Thickness	U_g, max, in. (mm)
under 2 in. (50 mm)	0.020 (0.50)
2 through 3 in. (50 through 75 mm)	0.030 (0.75)
over 3 through 4 in. (75 through 100 mm)	0.040 (1.00)
greater than 4 in. (100 mm)	0.070 (1.75)

Determine geometric unsharpness values as specified in Guide E 94.

9.4 *Examination Speed* — For dynamic examination, determine the speed of object motion relative to the radiation source and detector upon agreement between the purchaser and supplier. Base this determination upon the achievement of the required radioscopic quality level at that examination speed.

9.5 *Direction of the Radiation* — Direct the central beam of radiation perpendicularly toward the center of the effective area of the detector or to a plane tangent to the center of the image, to the maximum extent possible, except for double-wall exposure-double-wall viewing elliptical projection techniques, as described in 9.14.2.

9.6 *Scattered Radiation* — Scattered radiation (radiation scattered from the test object and from surrounding structures) reduces radioscopic contrast and may produce undesirable effects on radioscopic quality. Use precautions such as collimation of the source, collimation of the detector, and additional shielding as appropriate to minimize the detrimental effects of this scattered radiation.

9.7 *Image Quality Indicator Selection* — For selection of the image quality indicator, the thickness on which the image quality indicator is based is the single-wall thickness plus the lesser of the actual or allowable reinforcement. Backing strips or rings are not considered as part of the weld or reinforcement thickness for image quality indicator selection. For any thickness, an image quality indicator acceptable for thinner materials may be used, provided all other requirements for radioscopy are met.

9.8 *Number of Image Quality Indicators:*

9.8.1 Place at least one image quality indicator (Practices E 747 or E 1025) in the area of interest representing an area in which the brightness is relatively uniform. The degree of brightness uniformity shall be agreed upon between purchaser and supplier. If the image brightness in an area of interest differs by more than the agreed amount, use two image quality indicators. Use one image quality indicator to demonstrate acceptable image quality in the darkest portion of the image and use one image quality indicator to demonstrate acceptable image quality in the lightest portion of the image.

9.8.2 When a series of images are made under identical conditions, it is permissible for the image quality indicators to be used only on the first and last images in the series, provided this is agreed upon between the purchaser and supplier. In this case, it is not necessary for the image quality indicators to appear in each image.

9.8.3 Always retain qualifying images, on which one or more image quality indicators were imaged during exposure, as part of the record to validate the required image quality indicator sensitivity and placement.

9.9 *Image Quality Indicator Placement:*

9.9.1 Place the image quality indicator on the source side adjacent to the weld being examined. Where the weld metal is not radioscopically similar to the base material or where geometry precludes placement adjacent to the weld, place the image quality indicator over the weld or on a separate block, as described in 9.10.

9.9.2 *Detector-Side Image Quality Indicators* — In those cases where the physical placement of the image quality indicators on the source side is not possible, place the image quality indicators on the detector side. The applicable job order or contract shall specify the applicable detector-side quality level. The

accompanying documents shall clearly indicate that the image quality indicators were located on the detector side.

9.10 *Separate Block* — When configuration or size prevents placing the image quality indicators on the object being examined, use a shim, separate block or like section conforming to the requirements of 5.8 provided the following conditions are met:

9.10.1 The image quality indicator is no closer to the detector than the source side of the object being examined (unless otherwise specified).

9.10.2 The radioscopic brightness in the area of the image quality indicator including the shim, separate block, or like section and IQI where applicable are similar to the brightness in the area of interest.

9.10.3 The shim, separate block, or like section is placed as close as possible to the object being examined.

9.10.4 When hole-type image quality indicators are used, the shim, separate block, or like section dimensions shall exceed the image quality indicator dimensions such that the outline of at least three sides of the image quality indicator image is visible on the image.

9.11 *Shim Utilization* — When a weld reinforcement or backing ring and strip is not removed, place a shim of material that is radioscopically similar to the backing ring and strip under the image quality indicators to provide approximately the same thickness of material under the image quality indicator as the average thickness of the weld reinforcement plus the wall thickness, backing ring and strip.

9.11.1 *Shim Dimensions and Location* — When hole-type image quality indicators are used, the shim dimensions and location shall exceed the image quality indicator dimensions by at least 0.12 in. (3 mm) on at least three sides. At least three sides of the image quality indicator shall be discernible in accordance with 9.10.4 except that only the two ends of the image quality indicator need to be discernible when located on piping less than 1 in. (25 mm) nominal pipe size. Place the shim so as not to overlap the weld image including the backing strip or ring.

9.11.2 *Shim Image Brightness* — The image brightness of the shim image shall be similar to the image brightness of the area of interest.

9.12 *Location Markers* — Place location markers outside the weld area. The radioscopic image of the location markers for the identification of the part location with the image shall appear on the image without interfering with the interpretation and with such an arrangement that it is evident that complete coverage was obtained.

9.12.1 *Double-Wall Technique* — When using a technique in which radiation passes through two walls and the welds in both walls are simultaneously viewed for acceptance, and the entire image of the object being examined is displayed, only one location marker is required in the image.

9.12.2 *Series of Images* — For welds that require a series of images to cover the full length or circumference of the weld, apply the complete set of location markers at one time, wherever possible. A reference or zero position for each series must be identified on the component. A known feature on the object (for example, keyway, nozzle, and axis line) may also be used for establishment of a reference position. Indicate this feature on the radioscopic record.

9.12.3 *Similar Welds* — On similar type welds on a single component, the sequence and spacing of the location markers must conform to a uniform system that shall be positively identified in the radioscopic procedure or interpretation records. In addition, reference points on the component will be shown on the sketch to indicate the direction of the numbering system.

9.13 *Image Identification* — Provide a system of positive identification of the image. As a minimum, the following shall appear on the image: the name or symbol of the company performing radioscopy, the date, and the weld identification number traceable to part and contract. Identify subsequent images made of a repaired area with the letter "R."

9.14 *Radioscopic Techniques:*

9.14.1 *Single-Wall Technique* — Except as provided in 9.14.2, 9.14.3, and 9.14.4, perform radioscopy using a technique in which the radiation passes through only one wall.

9.14.2 *Double-Wall Technique for Circumferential Welds* — For circumferential welds 4 in. (100 mm) outside diameter (3.5 in. nominal pipe size) or less, use a technique in which the radiation passes through both walls and both walls are viewed for acceptance on the same image. Unless otherwise specified, either elliptical or superimposed projections may be used. A sufficient number of views should be taken to examine the entire weld. Where design or access restricts a practical technique from examining the entire weld,

agreement between contracting parties must specify necessary weld coverage.

9.14.3 For circumferential welds greater than 4 in. (100 mm) outside diameter (3.5 in. nominal pipe size), use a technique in which only single-wall viewing is performed. A sufficient number of views should be taken to examine the entire weld. Where design or access restricts a practical technique from examining the entire weld, agreement between contracting parties must specify necessary weld coverage.

9.14.4 For radioscopic techniques that prevent single-wall exposures due to restricted access, such as jacketed pipe or ship hull, the technique should be agreed upon in advance between the purchaser and supplier. It should be recognized that image quality indicator sensitivities based on single-wall thickness may not be obtainable under some conditions.

10. Records

10.1 Maintain the following radioscopic records as agreed between purchaser and supplier:

10.1.1 Radioscopic standard shooting sketch, including examination geometry, source-to-object distance, object-to-detector distance and orientation,

10.1.2 Material and thickness range examined,

10.1.3 Equipment used, including specification of source parameters (such as tube voltage, current, focal spot size) and imaging equipment parameters (such as detector size, field of view, electronic magnification, camera blacklevel, gain, etc.) and display parameters,

10.1.4 Image quality indicator (and shim, if used) placement,

10.1.5 Test-object scan plan, including ranges of motion and manipulation speeds,

10.1.6 Image processing parameters,

10.1.7 Image-storage data,

10.1.8 Weld repair documentation, and

10.1.9 *Image* — Interpretation record shall contain as a minimum the following information:

10.1.9.1 Disposition of each image (acceptable or rejectable),

10.1.9.2 If rejectable, cause for rejection (slag, crack, porosity, etc.),

10.1.9.3 Surface indication verified by visual examination (grinding marks, weld ripple, spatter, etc.), and

10.1.9.4 Signature of the image interpreter, including level.

11. Precision and Bias

11.1 No statement is made about either precision or bias of this test method since the result merely states whether there is conformance to the criteria of success specified in the procedure.

12. Keywords

12.1 gamma ray; nondestructive testing; radioscopic examination; radioscopy; weldments; x-ray

STANDARD PRACTICE FOR DETERMINING CONTRAST SENSITIVITY IN RADIOSCOPY 01

SE-1647

(Identical with ASTM Specification E 1647-98a)

1. Scope

1.1 This practice covers the design and material selection of a contrast sensitivity measuring gage used to determine the minimum material thickness or density that may be imaged without regard to spatial resolution limitations.

1.2 This practice is applicable to transmitted-beam radioscopic imaging systems utilizing X-ray and gamma ray radiation sources.

1.3 The values stated in inch-pound units are to be regarded as standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific safety statements, see NIST/ANSI Handbook 114 Section 8, Code of Federal Regulations 21 CFR 1020.40 and 29 CFR 1910.96.

2. Referenced Documents

2.1 *ASTM Standards:*

B 139 Specification for Phosphor Bronze Rod, Bar, and Shapes
B 150 Specification for Aluminum Bronze Rod, Bar, and Shapes
B 161 Specification for Nickel Seamless Pipe and Tube
B 164 Specification for Nickel-Copper Alloy Rod, Bar, and Wire
B 166 Specification for Nickel-Chromium-Iron Alloys (UNS N06600, N06601, and N06690) and Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617) Rod, Bar, and Wire
E 747 Practice for the Design Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used For Radiology
E 1316 Terminology for Nondestructive Examination
E 1025 Practice for Hole-Type Image Quality Indicators Used for Radiography
E 1411 Practice for Qualification of Radioscopic Systems

2.2 *Federal Standards:*

21 CFR 1020.40 Safety Requirements for Cabinet X-ray Systems
29 CFR 1910.96 Ionizing Radiation

2.3 *NIST/ANSI Standards:*

NIST/ANSI Handbook 114 General Safety Standard for Installations Using Non-Medical X-ray and Sealed Gamma Ray Sources, Energies to 10 MeV

2.4 *Other Standard:*

EN 462-5 Duplex Wire Image Quality Indicator

3. Terminology

3.1 *Definitions* — Definitions of terms applicable to this test method may be found in Terminology E 1316.

4. Summary of Practice

4.1 It is often useful to evaluate the contrast sensitivity of a penetrating radiation imaging system separate and apart from spatial resolution measurements. Conventional image quality indicators (IQIs), such as Test Method E 747 wire and Practice E 1025 plaque IQIs, combine the contrast sensitivity and resolution measurements into an overall performance figure of merit. Such figures of merit are often not adequate to detect subtle changes in imaging system performance. For example, in a high contrast image, spatial resolution can degrade

with almost no noticeable effect upon overall image quality. Similarly, in an application in which the imaging system provides a very sharp image, contrast can fade with little noticeable effect upon the overall image quality. These situations often develop and may go unnoticed until the system performance deteriorates below acceptable image quality limits.

5. Significance and Use

5.1 The contrast sensitivity gage measures contrast sensitivity independent of the imaging system spatial resolution limitations. The thickness recess dimensions of the contrast sensitivity gage are large with respect to the spatial resolution limitations of most imaging systems. Four levels of contrast sensitivity are measured: 4%, 3%, 2%, and 1%.

5.2 The contrast sensitivity gage is intended for use in conjunction with a high-contrast resolution measuring gage, such as the EN 462-5 Duplex Wire Image Quality Indicator. Such gages measure spatial resolution essentially independent of the imaging system's contrast sensitivity. Such measurements are appropriate for the qualification and performance monitoring of radiographic and radioscopic imaging systems.

5.3 Radioscopic system performance may be specified by combining the measured contrast sensitivity expressed as a percentage with the spatial resolution expressed in millimeters of unsharpness. For the EN 462-5 spatial resolution gage, the unsharpness is equal to twice the wire diameter. For the line pair gage, the unsharpness is equal to the reciprocal of the line-pair/mm value. As an example, an imaging system that exhibits 2% contrast sensitivity and images the 0.1 mm EN 462-5 paired wires (equivalent to imaging 5 line-pairs/millimeter resolution on a line-pair gage) performs at a 2%–0.2 mm sensitivity level. A standard method of evaluating overall radioscopic system performance is given in Practice E 1411.

TABLE 1
DESIGN OF THE CONTRAST SENSITIVITY GAGE

Gage Thickness	J Recess	K Recess	L Recess	M Recess
T	1% of T	2% of T	3% of T	4% of T

TABLE 2
CONTRAST SENSITIVITY GAGE DIMENSIONS

Gage Size	B DIM.	C DIM.	D DIM.	E DIM.	F,G DIM.
1	0.750 in. 19.05 mm	3.000 in. 76.20 mm	0.250 in. 6.35 mm	0.625 in. 15.88 mm	0.250 in. 6.35 mm
2	1.500 in. 38.10 mm	6.000 in. 152.40 mm	0.500 in. 12.70 mm	1.250 in. 31.75 mm	0.500 in. 12.7 mm
3	2.250 in. 57.15 mm	9.000 in. 228.60 mm	0.750 in. 19.05 mm	1.875 in. 47.63 mm	0.750 in. 19.05 mm
4	3.000 in. 76.20 mm	12.000 in. 304.80 mm	1.000 in. 25.40 mm	2.500 in. 63.50 mm	1.000 in. 25.4 mm

TABLE 3
CONTRAST SENSITIVITY GAGE APPLICATION

Gage Size	Use on Thicknesses
1	Up to 1.5 in. (38.1 mm)
2	Over 1.5 in. (38.1 mm) to 3.0 in. (76.2 mm)
3	Over 3.0 in. (76.2 mm) to 6.0 in. (152.4 mm)
4	Over 6.0 in. (152.4 mm)

6. Contrast Sensitivity Gage Construction and Material Selection

6.1 Contrast sensitivity gages shall be fabricated in accordance with Fig. 1, using the dimensions given in Tables 1, 2, and 3.

6.2 The gage shall preferably be fabricated from the test object material. Otherwise, the following material selection guidelines are to be used:

6.2.1 Materials are designated in eight groupings, in accordance with their penetrating radiation absorption characteristics: groups 03, 02, and 01 for light metals and groups 1 through 5 for heavy metals.

6.2.2 The light metal groups, magnesium (Mg), aluminum (Al), and titanium (Ti), are identified 03, 02, and 01, respectively, for their predominant constituent. The materials are listed in order of increasing radiation absorption.

6.2.3 The heavy metals group, steel, copper base, nickel base, and other alloys, are identified 1 through 5. The materials increase in radiation absorption with increasing numerical designation.

6.2.4 Common trade names or alloy designations have been used for clarification of pertinent materials.

6.3 The materials from which the contrast sensitivity gage is to be made is designated by group number. The gage is applicable to all materials in that group. Material groupings are as follows:

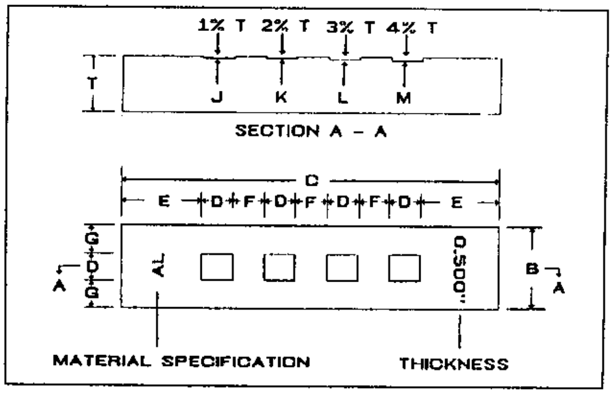


FIG. 1 GENERAL LAYOUT OF THE CONTRAST SENSITIVITY GAGE

6.3.1 *Material Group 03:*

6.3.1.1 The gage shall be made of magnesium or a magnesium alloy, provided it is no more radio-opaque than unalloyed magnesium, as determined by the method outlined in 6.4.

6.3.1.2 Use for all alloys where magnesium is the predominant alloying constituent.

6.3.2 *Materials Group 02:*

6.3.2.1 The gage shall be made of aluminum or an aluminum alloy, provided it is no more radio-opaque than unalloyed aluminum, as determined by the method outlined in 6.4.

6.3.2.2 Use for all alloys where aluminum is the predominant alloying constituent.

6.3.3 *Materials Group 01:*

6.3.3.1 The gage shall be made of titanium or a titanium alloy, provided it is no more radio-opaque than unalloyed titanium, as determined by the method outlined in 6.4.

6.3.3.2 Use for all alloys where titanium is the predominant alloying constituent.

6.3.4 *Materials Group 1:*

6.3.4.1 The gage shall be made of carbon steel or Type 300 series stainless steel.

6.3.4.2 Use for all carbon steel, low-alloy steels, stainless steels, and magnesium-nickel-aluminum bronze (Superston).

6.3.5 *Materials Group 2:*

6.3.5.1 The gage shall be made of aluminum bronze (Alloy No. 623 of Specification B 150) or equivalent or nickel-aluminum bronze (Alloy No. 630 of Specification B 150) or equivalent.

6.3.5.2 Use for all aluminum bronzes and all nickel aluminum bronzes.

6.3.6 *Materials Group 3:*

6.3.6.1 The gage shall be made of nickel-chromium-iron alloy (UNS No. N06600) (Inconel). See Specification B 166.

6.3.6.2 Use for nickel-chromium-iron alloy and 18% nickel-maraging steel.

6.3.7 *Materials Group 4:*

6.3.7.1 The gage shall be made of 70 to 30 nickel-copper alloy (Monel) (Class A or B of Specification B 164) or equivalent, or 70 to 30 copper-nickel alloy (Alloy G of Specification B 161) or equivalent.

6.3.7.2 Use for nickel, copper, all nickel-copper series or copper-nickel series of alloys and all brasses (copper-zinc alloys) and all leaded brasses.

6.3.8 *Materials Group 5:*

6.3.8.1 The gage shall be made of tin-bronze (Alloy D of Specification B 139).

6.3.8.2 Use for tin bronzes including gun-metal and valve bronze and leaded-tin bronzes.

6.4 Where the material to be examined is a composite ceramic, or other nonmetallic material, or for some reason cannot be obtained to fabricate a gage, an

equivalent material may be utilized, provided it is no more radio-opaque than the test object under comparable penetrating radiation energy conditions. To determine the suitability of a substitute material, radiograph identical thicknesses of both materials on one film using the lowest penetrating radiation energy to be used in the actual examination. Transmission densitometer readings for both materials shall be in the range from 2.0 to 4.0. If the radiographic density of the substitute material is within +15% to −0% of the test material, the substitute material is acceptable.

6.4.1 All contrast sensitivity gages shall be suitably marked by vibro-engraving or etching. The gage thickness and material type shall be clearly marked.

7. Imaging System Performance Levels

7.1 Imaging system performance levels are designated by a two-part measurement expressed as C(%) — U(mm). The first part of the expression C(%) refers to the depth of the shallowest flat-bottom hole that can be reliably and repeatably imaged. The second part of the expression refers to the companion spatial resolution measurement made with a resolution gage expressed in terms of millimeters unsharpness. Where contrast sensitivity is measured for both thin and thick section performance, the performance level is expressed as $C_{min}(\%)-C_{max}(\%)-U(mm)$.

7.2 Each contrast sensitivity gage has four flat-bottom recesses that represent 1%, 2%, 3%, and 4% of the gage total thickness. The shallowest recess that can be repeatably and reliably imaged shall determine the limiting contrast sensitivity.

7.3 Contrast sensitivity measurements shall be made under conditions as nearly identical to the actual examination as possible. Penetrating radiation energy, image formation, processing, analysis, display, and viewing variables shall accurately simulate the actual examination environment.

8. Contrast Sensitivity Gage Measurement Steps (see Table 1)

8.1 The gage thickness T shall be within ±5% of the test object thickness value at which contrast sensitivity is being determined.

8.2 The gage thickness tolerance shall be within ±1% of the gage design thickness T or 0.001 in. (0.02 mm), whichever is greater.

8.3 The gage recess depth tolerance shall be within ±10% of the design value for the shallowest recess or 0.001 in. (0.02 mm), whichever is greater.

8.4 The gage recess inside and outside corner radius shall not exceed 0.062 in. (1.80 mm). To facilitate fabrication, the gage may be assembled from three individually machined components: (*1*) the machined center section containing the 1% *T*, 2% *T*, 3% *T*, and 4% *T* milled slots; (*2*) the front rail, and (*3*) the rear rail. The assemblage of the three components forms the complete gage similar to that shown in Appendix X1.

8.5 The gage dimensional tolerances shall be held to within ±0.010 in. (0.25 mm) of the dimensions specified in Table 2.

9. Acceptable Performance Levels

9.1 Nothing in this test method implies a mandatory or an acceptable contrast sensitivity performance level. That determination is to be agreed upon between the supplier and user of penetrating radiation examination services.

9.2 The recess depths specified in Table 1 provide measurement points at 1%, 2%, 3%, and 4% that will accommodate many imaging system configurations. Other contrast sensitivity measurement points may be obtained by placing the gage on a shim made of the gage material. The resulting contrast sensitivity measurement expressed as a percentage is given by the following formula:

$$\% \text{ Contrast} = \frac{R}{T+S} \times 100$$

where:
R = recess depth,
S = shim thickness, and
T = gage thickness.

If other recess depths are required to document radioscopic system performance, special contrast sensitivity gages may be fabricated by changing the recess depths specified in Table 1 to suit the need.

10. Performance Measurement Records

10.1 The results of the contrast sensitivity measurement should be recorded and maintained as a part of the initial qualification and performance monitoring records for the imaging system. Changes in contrast sensitivity can be an early indicator of deteriorating imaging system performance.

11. Precision and Bias

11.1 No statement is made about the precision or bias for indicating the contrast sensitivity of a radioscopic system using the contrast sensitivity gage described by this test method.

12. Keywords

12.1 contrast sensitivity gage; gamma ray; image formation; image processing; image quality indicator; line-pairs per millimeter; penetrating radiation; spatial resolution; X-ray

APPENDIX
(Nonmandatory Information)

X1. ASSEMBLING THE CONTRAST SENSITIVITY GAGE

X1.1 Suggested method of assembling the contrast sensitivity gage from a milled center section with front and rear rails attached to form the complete contrast sensitivity gage. The example shown (see Fig. X1.1) is for use with a 0.500 in. thick test object.

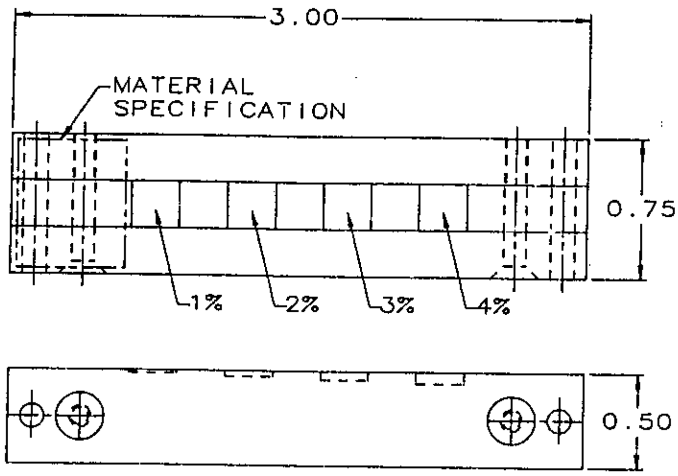


FIG. X1.1 CONTRAST SENSITIVITY GAGE

STANDARD TEST METHOD FOR CLASSIFICATION OF FILM SYSTEMS FOR INDUSTRIAL RADIOGRAPHY

SE-1815

(Identical with ASTM Specification E 1815-96)

1. Scope

1.1 This test method covers a procedure for determination of the performance of film systems used for industrial radiography. This test method establishes minimum requirements that correspond to system classes.

1.2 This test method is to be used only for direct exposure-type film exposed with lead intensifying screens. The performance of films exposed with fluorescent (light-emitting) intensifying screens cannot be determined accurately by this test method.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 94 Guide for Radiographic Testing

E 999 Guide for Controlling the Quality of Industrial Radiographic Film Processing

E 1079 Practice for Calibration of Transmission Densitometers

E 1316 Terminology for Nondestructive Examinations

2.2 *ANSI Standards:*

PH 2.18 Photography (Sensitometry) — Density Measurements, Spectral Conditions

PH 2.19 Photography Density Measurements — Part 2: Geometric Conditions for Transmission Density

PH 2.40 Root Mean Square (rms) Granularity of Film (Images on One Side Only) Method of Measuring

2.3 *ISO Standards:*

ISO 5-2 Photography Density Measurements — Part 2: Geometric Conditions for Transmission Density

ISO 5-3 Photography Density Measurements — Part 3: Spectral Conditions

ISO 7004 Photography — Industrial Radiographic Film, Determination of ISO Speed and Average Gradient When Exposed to X and Gamma Radiation

3. Terminology

3.1 *Definitions* — For definitions of terms used in this test method, refer to Terminology SE-1316.

3.2 *Descriptions of Terms Specific to This Standard:*

3.2.1 *film system* — the film and associated film-processing requirements according to the criteria established by the manufacturers of the film and processing chemicals.

3.2.2 *gradient G* — the slope of the characteristic curve at a certain density, *D*, and a measure of the contrast of the film system.

3.2.3 *granularity, σ_D* — the stochastic density fluctuations in the radiograph that are superimposed to the object image.

3.2.4 *ISO speed S* — determined by the dose K_s, measured in gray at a specified optical density, *D*, in the radiograph.

TABLE 1
TYPICAL FILM SYSTEM CLASSIFICATION

Automatic Film Processing
Developer: Type A
Developer immersion time: XXX seconds
Developer temperature: XX°C/YY°F

Film Type[A]	ASTM System Class	Maximum Gradient G at $D = 2.0$ Above D_o	Maximum Gradient G at $D = 4.0$ Above D_o	Maximum Gradient/ Granularity Ratio, G/σ_D, at $D = 2.0$ Above D_o	Maximum Granularity, σ_D, at $D = 2.0$ Above D_o	ISO Speed S	Dose, K_s m Gy, $D = 2.0$
A	Special	5.4	9.1	360	0.015	32	29.0
B	I	4.5	8.4	281	0.016	64	14.0
C	I	4.4	7.6	232	0.019	100	8.7
D	I	4.4	7.6	169	0.026	200	4.6
E	II	4.4	7.6	142	0.031	320	3.2
F	III	4.0	5.2	114	0.035	400	2.5
G	W-A	4.2	6.5	225	0.019	100	8.6
H	W-B	4.1	5.3	170	0.025	300	5.0

[A] Family of films ranging in speed and image quality.

4. Significance and Use

4.1 This test method provides a relative means for classification of film systems used for industrial radiography. The film system consists of the film and associated processing system (the type of processing and processing chemistry). Section 6 describes specific parameters used for this test method. In general, the classification for hard X rays, as described in Section 6, can be transferred to other radiation energies and metallic screen types, as well as screens without films. The usage of film system parameters outside the energy ranges specified may result in changes to a film/system performance classification.

4.1.1 The film performance is described by signal and noise parameters. The signal is represented by gradient and the noise by granularity.

4.1.2 A film is assigned a particular class if it meets all four of the minimum performance parameters: for Gradient G at $D = 2.0$ and $D = 4.0$, granularity σ_D at $D = 2.0$, and gradient/noise ratio at $D = 2.0$.

4.2 This test method describes how the parameters shall be measured and demonstrates how a classification table can be constructed.

4.3 Manufacturers of industrial radiographic film systems will be the users of this test method. The result is a classification table as shown by the example given in Table 1. This table also includes speed data for user information. Users of industrial radiographic film systems may also perform the tests and measurements outlined in this test method, provided that the required test equipment is used and the methodology is followed strictly.

4.4 The publication of classes for industrial radiography film systems will enable specifying bodies and contracting parties to agree to particular system classes, which are capable of providing known image qualities. See 7.2.

5. Sampling and Storage

5.1 For determination of the gradient and granularity of a film system, it is important that the samples evaluated yield the average results obtained by users. This will require evaluating several different batches periodically, under the conditions specified in this test method. Prior to evaluation, the samples shall be stored according to the manufacturer's recommendations for a length of time to simulate the average age at which the product is normally used. Several independent evaluations shall be made to ensure the proper calibration of equipment and processes. The basic objective in selecting and storing samples as described above is to ensure that the film characteristics are representative of those obtained by a consumer at the time of use.

6. Procedure

6.1 *Principle:*

6.1.1 Film to be tested shall be exposed to X rays from tungsten target tubes. Inherent filtration of the tube, plus an additional copper filter located as close to the target as possible, shall provide filtration equivalent to 8.00 ± 0.2 mm of copper.

6.1.2 The film system includes a front and a back screen of 0.02 to 0.25-mm lead. If single-coated films are used, the emulsion-coated surface must face the X-ray tube. Vacuum or pressure cassettes may be used to ensure sufficient contact between the film and screen.

6.2 *X-ray Spectral Quality:*

6.2.1 Use the same X-ray spectral quality for determining both the film gradient and its root mean square granularity. Make the film exposures with an 8-mm (0.32-in.) copper filter at the X-ray tube and the kilovoltage set such that the half value layer in copper is 3.5 mm (0.14 in.). The kilovoltage setting will be approximately 220 kV.

6.2.2 Determine the required kilovoltage setting by making an exposure (or exposure rate) measurement with the detector placed at a distance of at least 750 mm (29.5 in.) from the tube target and an 8-mm (0.32-in.) copper filter at the tube. Then make a second measurement with a total of 11.5 mm (0.45 in.) of copper at the tube. These filters should be made of 99.9% pure copper.

6.2.3 Calculate the ratio of the first and second readings. If this ratio is not 2, adjust the kilovoltage up or down and repeat the measurements until a ratio of 2 (within 5%) is obtained. Record the machine setting of the kilovoltage for use with the film tests.

6.3 *Film Cassette and Screens:*

6.3.1 The film cassette (holder) shall provide a means of ensuring good film screen contact. A vacuum cassette may be used.

6.3.2 Lead-foil screens shall be used with the front screen thickness being 0.130 ± 0.013 mm (0.005 ± 0.05 in.) and the back screen thickness being 0.250 ± 0.025 mm (0.010 ± 0.001 in.).

NOTE — These thicknesses reflect commercially available tolerances in lead foil for use as radiographic screens.

6.3.3 It is especially important that the exposure to the film specimen for the granularity measurements be spatially uniform. Any nonuniformities in X-ray transmission of the cassette front or nonuniformities or defects in the lead-foil screens could influence the granularity measurement. Therefore, exercise considerable care in selection and maintenance of the cassette and lead screens to minimize these effects.

6.3.4 Expose single-coated films with the emulsion-coated surface in contact with the front screen.

6.4 *Film Processing* — The film image quality will vary with the processing variables, such as chemistry, temperature, and method of processing (manual or automatic). The film processing and record requirements shall be in accordance with Guide E 999.

6.5 *Exposure Conditions:*

6.5.1 The plane of the film shall be normal to the central ray of the X-ray beam. Use a diaphragm at the tube to limit the field of radiation to the film area. The X-ray tube target to film distance shall be adequate to ensure that the exposure over the useful area of each exposure step is uniform to within 3%.

6.5.2 To minimize the effects of backscattered radiation, use a 6.3 ± 0.8 mm ($^1/_4$ ± $^1/_{32}$ in.) thick lead shielding behind the cassette. The shielding lead shall extend at least 25 mm (1 in.) beyond each edge of the cassette. Alternatively, the shielding lead may be omitted, provided that the cassette is supported such that the X-ray beam strikes no scattering material, other than air, for a distance of at least 2 m (78.7 in.) behind the cassette.

6.5.3 Modulation of the X-ray exposure may be accomplished by changing the exposure time or tube target to film distance. Changing the tube current is not recommended but may be done, provided it is verified by measurement (see 6.2) that the X-ray spectral quality does not change.

6.5.4 Measure exposures with an air-ionization chamber, or other types of X-ray detectors, having linear response over the range of X-ray intensities and exposure times used for the film exposures.

6.5.5 During and after exposure, prior to processing, keep the film at a temperature of 23 ± 5°C (5.97 ± 5°F) and a relative humidity of 50 ± 20%. Start processing of the film between 30 min and 8 h after exposure. Process an unexposed specimen of the film sample with the X-ray-exposed specimen in order to determine the base plus fog density.

6.5.6 Measure the visual diffuse transmission density of the processed films with a densitometer complying with the requirements of ANSI PH 2.19 and ISO

5-2 and calibrated by the method of Practice E 1079. Use a minimum aperture of 7 mm (0.275 in.).

6.6 *Measurement of Gradient G:*

6.6.1 Gradient G relates to a D versus log K curve. In the scope of this test method, G is calculated from the slope of a D versus K curve at density ($D - D_o$), as follows:

$$G = \frac{dD}{d \log K} = \frac{K}{\log e} \times \frac{dD}{dK}$$

where:

K = dose required for density $D - D_o$, and

D_o = fog and base density.

6.6.2 The D versus K curve is approximated by a polynomial of the third order. To obtain a regular and reliable shape of this curve, make a series of exposures to obtain at least 12 uniformly distributed measuring points between density 1.0 and 5.0 above D_o.

6.6.3 Average the Gradient G measurements, with a maximum inaccuracy of ±5%.

6.7 *Root Mean Square (rms) Granularity, σ_D:*

6.7.1 Determine the rms granularity of the film in accordance with ANSI PH 2.40, with the following exceptions:

6.7.2 The procedure is limited to the measurement of continuous tone black-and-white industrial X-ray films viewed by transmitted light. The film may have emulsion coated on one side or both sides of the film support.

6.7.3 Expose the film specimen with X rays having the spectral quality described in 6.2. The cassette and lead-foil screens shall be as specified in 6.3. Expose the film specimen in accordance with the exposure conditions of 6.5. Exercise care to ensure that the film specimen does not contain density variations arising from the exposing equipment (such as nonuniform beam filters or damaged or defective lead screens). During and after exposure, prior to processing, maintain the film specimen at the temperature and relative humidity conditions specified in 6.5.5. The film processing chemicals and procedures shall be the same as those used for determining gradient, and they shall be described completely as specified in 6.4.

6.7.4 The film specimen for granularity measurement shall have a diffuse density of 2.00 ± 0.05 above base plus fog. As an alternative, three or more samples of the film specimen at different density levels, within the range from 1.80 to 2.20, may be measured, and the granularity value at a diffuse density of 2.00, above base plus fog, shall be taken from a smooth curve drawn through a plot of the data points. The granularity value shall be in terms of diffuse density.

6.7.4.1 The microdensitometer scanner output is measured as projection density. Thus to obtain the desired diffuse density, convert the data using the slope of the curve of diffuse density versus projection density at the mean density value of the granularity film specimen. Determine this curve using a film having a stepped series of densities, which is prepared using the same type film, exposure, and processing techniques as used for the granularity film specimen. Measure the diffuse density of each step with a microdensitometer. The specimen film shall be scanned using identical microdensitometer settings. A limited range of densities can typically be measured for a given microdensitometer gain setting. The stepped series of densities shall lie within that range. Choose the number of steps such that the slope of the curve, at the mean density of the granularity film specimen, is determined to an accuracy of ±5%.

6.7.5 Determine the granularity of the film specimen by evaluating no fewer than three samples of the specimen and determining their mean so that a maximal uncertainty of 10% is achieved.

6.7.6 Adjust the optical system of the microdensitometer so that both emulsions, or the one emulsion in the case of a single-coated film, are in focus at all points in the scan.

6.7.7 Scan the film specimen along three different paths within the test area. Take the median of the three granularity readings as the granularity of the film specimen at the mean measured density.

6.7.8 *Microdensitometer Requirements:*

6.7.8.1 The influx aperture of the microdensitometer shall be approximately circular in shape, with a diameter (referred to the plane of the specimen) not less than 1.2× or more than 2× the diameter of the efflux aperture.

6.7.8.2 Both the influx objective and the efflux objective shall be a high-quality microscope objective having a numerical aperture no greater than 0.10.

6.7.8.3 The reduction of the influx aperture by the influx optics and the magnification of the specimen onto the efflux aperture by the efflux optics shall lie

TABLE 2
DETERMINATION OF ISO SPEED S FROM DOSE, K_s, NEEDED FOR A FILM DENSITY, D = 2.0, ABOVE D_o

$\log_{10}K_s$		
From	To	ISO Speed S[A]
−3.05	−2.96	1000
−2.95	−2.86	800
−2.85	−2.76	640
−2.75	−2.66	500
−2.65	−2.56	400
−2.55	−2.46	320
−2.45	−2.36	250
−2.35	−2.26	200
−2.25	−2.16	160
−2.15	−2.06	125
−2.05	−1.96	100
−1.95	−1.86	80
−1.85	−1.76	64
−1.75	−1.66	50
−1.65	−1.56	40
−1.55	−1.46	32
−1.45	−1.36	25
−1.35	−1.26	20
−1.25	−1.16	16
−1.15	−1.06	12
−1.05	−0.96	10
−0.95	−0.86	8
−0.85	−0.76	6
−0.75	−0.66	5
−0.65	−0.56	4

[A] See ISO 7004.

TABLE 3
LIMITING VALUES FOR GRADIENT, GRADIENT/GRANULARITY RATIO, AND GRANULARITY

ASTM System Class	Minimum Gradient G at D = 2.0 Above D_o[A]	Minimum Gradient G at D = 4.0 Above D_o	Minimum Gradient/Granularity Ratio, G/σ_D at D = 2.0 Above D_o	Maximum Granularity, σ_D, at D = 2.0 Above D_o
Special	4.5	7.5	300	0.018
I	4.1	6.8	150	0.028
II	3.8	6.4	120	0.032
III	3.5	5.0	100	0.039
W-A	3.6	5.7	135	0.027
W-B	3.5	5.0	110	0.032
W-C	<3.5	<5.0	80	0.039

[A] D_o = density of an unexposed and processed film including base (fog and base density).

in the range from 20 to 100×. The two magnifications need not be equal.

6.7.8.4 The efflux (or measuring aperture) shall be circular in shape. Its effective diameter referred to the specimen plane shall be 100 ± 2 μm.

6.7.8.5 The scan path of the microdensitometer may be linear or circular. If circular, the radius of the path shall not be less than 16 mm. In either case, the total scan length shall not be less than 100 mm (3.94 in.).

6.7.8.6 The spectral response of the microdensitometer system shall be visual, as specified by ANSI PH 2.18 and ISO 5-3.

6.7.8.7 The electronic band-pass filter, used to reduce the unwanted signal caused by system artifacts, shall have its low-frequency boundary set so the system response is 3 dB down at a temporal frequency corresponding to a spatial frequency of 0.1 cycles/mm. Its high-frequency boundary shall be set so that the system response is 3 dB down at a temporal frequency corresponding to the first zero in the spatial frequency response of the circular aperture. Mathematical procedures that can be shown to produce equivalent reductions in the effects of system artifacts are acceptable alternatives to the use of this filter.

6.8 *Measurement of ISO Speed S* — The ISO Speed S is evaluated for an optical density, D = 2.0, above fog and base, D_o. Use Table 2 for determination of the ISO speed.

7. Range of Classification and Limiting Values

7.1 There are film system classes that differ by their gradients and granularities. The limiting values are assigned to the film classes whose observance must be proved by the measuring methods in 6.6 and 6.7.

7.1.1 In order to assign a film system to a system class, it must meet all four limiting values of the gradient (at D = 2.0 and D = 4.0), the granularity (at D = 2.0), and the gradient/granularity parameter of the system class. The classification is valid only for the complete film system.

7.2 Film system manufacturers will provide their classification table, upon request, with a classification table that contains full data on the four parameters according to Table 3. In addition, the following two parameters (see Table 2 for data) will be listed with the classification table: ISO speed S, and dose, K_s.

7.2.1 The classification table will additionally contain the following information on the processing system:

manual or automatic, type of chemistry, developer immersion time, and developer temperature.

7.3 For examples of a classification table, see Table 1.

8. Precision and Bias

8.1 No statement is made about either the precision or bias of this test method for measuring a film system classification of industrial radiographic film since the results state merely whether there is conformance to the criteria for success specified in the procedure.

9. Keywords

9.1 ASTM system class; film system; film system classification; gradient; gradient/noise; granularity; industrial radiographic film; speed.

APPENDIX

(Nonmandatory Information)

X1. GENERAL PRINCIPLES OF CLASSIFICATION

X1.1 The purpose of this test method is to classify industrial radiographic film systems based on their image quality performance over the practical working range of densities (for example, from 2.0 to 4.0). The classes are differentiated in image quality performance based on limiting values for four measurable image quality parameters, that is, gradient at density 2.0 and 4.0 and granularity and gradient/granularity ratio at density 2.0. See Table 3.

X1.1.1 The result of classification can be documented in a table with the following details:

X1.1.1.1 Description of the film system (film and processing),

X1.1.1.2 Values for four image quality parameters and the corresponding system class, and

X1.1.1.3 Speed of the film system.

X1.1.2 The optimal film system based on system classification (imaging performance) and speed (exposure time) can be selected with this information. See Table 1 for an example.

X1.2 *Significance of Classes*

X1.2.1 Various codes and specifications require film selection based on a class (Type 1, 2, or 3) from a version of Guide E 94 dated before 1984. In Guide E 94-83, speed, contrast, and graininess were specified as limiting values, but only in a subjective way. According to this guide, a range of films was classified in order of increasing speed and decreasing image quality (contrast and graininess). Image quality was optimized for a given speed.

X1.2.2 This test method has similar classes: Special, I, II, and III (see Table 3). The film systems that will generally fit this classification are of high-contrast technology. Image quality is optimized for every speed. Granularity increases with speed, and gradient is a maximum for the slower speed film systems.

X1.2.3 The slower film systems give the highest image quality, through a combination of low granularity and high gradient for both Density 2.0 and 4.0 and a corresponding high gradient/granularity ratio.

X1.2.4 Four classes of this test method were selected to correspond to the former film classification standard table of Guide E 94-83. See Table X1.1.

X1.2.5 Table X1.2 provides classification of wide latitude film systems. In comparison to traditional high-contrast technology, these film systems are generally characterized by a lower gradient for a given speed, producing wider exposure latitude and correspondingly lower image quality. The gradient will be lower at density 2.0 and significantly lower at high densities. Limiting values for image quality parameters are as follows (classes of wide-latitude film systems do not correspond directly to classes of former Guide E 94-83):

X1.2.6 The wide-latitude system classes are described as follows:

X1.2.6.1 *W-A and W-B* — Films with ASTM System Class III or better image quality. In general, these films use intermediate technology (between traditional high contrast and low contrast). Applications are judged by comparing all four image quality parameters.

TABLE X1.1
CLASSIFICATION COMPARISON OF TEST METHOD E 1815 AND GUIDE E 94-83 FOR HIGH-CONTRAST FILM SYSTEMS

Test Method SE-1815 System Class	Minimum Gradient G at D = 2.0	Minimum Gradient G at D = 4.0	Minimum Gradient/ Granularity Ratio at D = 2.0	Maximum Granularity at D = 2.0	Guide E 94-83 Film Type	Description: Speed	Description: Contrast	Description: Graininess
Special	4.5	7.5	300	0.018				
I	4.1	6.8	150	0.028	1	Low	Very high	Very low
II	3.8	6.4	120	0.032	2	Medium	High	Low
III	3.5	5.0	100	0.039	3	High	Medium	High

X1.2.6.2 *W-C* — Film systems with lower image quality performance than ASTM System Class III. In general, this is low-contrast (medical) film technology in combination with direct exposure technique.

NOTE X1.1 — The combination of Tables X1.1 and X1.2 corresponds to Table 3.

NOTE X1.2 — Fundamental differences between this test method and Guide E 94-83 are as follows: *(1)* with this test method, film systems are classified instead of film types (as in Guide E 94-83); and *(2)* in this test method, classification is based only on imaging performance. Speed is not a classification parameter.

TABLE X1.2
TEST METHOD E 1815 CLASSIFICATION OF WIDE-LATITUDE FILM SYSTEMS

Test Method SE-1815 Film System Class	Min. Gradient G at D = 2.0 Above D_0	Min. Gradient G at D = 4.0 Above D_0	Min. Gradient/ Granularity Ratio, G/σ_D, at D = 2.0 Above D_0	Max. Granularity, σ_D at D = 2.0 Above D_0
W-A	3.8	5.7	135	0.027
W-B	3.5	5.0	110	0.032
W-C	<3.5	<5.0	80	0.039

ARTICLE 23
ULTRASONIC STANDARDS

STANDARD PRACTICE FOR ULTRASONIC EXAMINATION OF HEAVY STEEL FORGINGS

SA-388/SA-388M

(Identical with ASTM Specification A 388/A 388M-95)

1. Scope

1.1 This practice covers the examination procedures for the contact, pulse-echo ultrasonic examination of heavy steel forgings by the straight- and angle-beam techniques. The straight-beam techniques include utilization of the DGS (Distance Gain Size) method. See Appendix X3.

1.2 This practice is to be used whenever the inquiry, contract, order, or specification states that forgings are to be subject to ultrasonic examination in accordance with Practice A 388/A 388M.

1.3 The values stated in either inch-pound or SI units are to be regarded as the standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.4 This specification and the applicable material specifications are expressed in both inch-pound units and SI units. However, unless the order specifies the applicable "M" specification designation (SI units), the material shall be furnished to inch-pound units.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 469 Specification for Vacuum-Treated Steel Forgings for Generator Rotors
A 745/A 745M Practice for Ultrasonic Examination of Austenitic Steel Forgings
E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems Without the Use of Electronic Measurement Instruments
E 428 Practice for Fabrication and Control of Steel Reference Blocks Used in Ultrasonic Inspection

2.2 *ANSI Standard:*

B46.1 Surface Texture

2.3 *Other Document:*

Recommended Practice for Nondestructive Personnel Qualification and Certification SNT-TC-1A, Supplement C — Ultrasonic Testing

3. Ordering Information

3.1 When this practice is to be applied to an inquiry, contract, or order, the purchaser shall so state and shall also furnish the following information:

3.1.1 Method of establishing the sensitivity in accordance with 7.2.2 and 7.3.3 (Vee or rectangular notch),

3.1.1.1 The diameter and test metal distance of the flat-bottom hole and the material of the reference block in accordance with 7.2.2.2,

3.1.2 Quality level for the entire forging or portions thereof in accordance with 10.3, and

3.1.3 Any options in accordance with 6.1, 6.2, and 7.1.10.

4. Apparatus

4.1 An ultrasonic, pulsed, reflection type of instrument shall be used for this examination. The system shall have a minimum capability for examining at frequencies from 1 to 5 MHz. On examining austenitic stainless forgings the system shall have the capabilities for examining at frequencies down to 0.4 MHz.

4.1.1 The ultrasonic instrument shall provide linear presentation (within 5%) for at least 75% of the screen height (sweep line to top of screen). The 5% linearity referred to is descriptive of the screen presentation of amplitude. Instrument linearity shall be verified in accordance with the intent of Practice E 317. Any set of blocks processed in accordance with Practice E 317 or E 428 may be used to establish the specified ± 5% instrument linearity.

4.1.2 The electronic apparatus shall contain an attenuator [accurate over its useful range to ± 10% (± 1 dB) of the amplitude ratio] which will allow measurement of indications beyond the linear range of the instrument.

4.2 *Search Units* having a transducer with a maximum active area of 1 in.^{2} [650 mm^2] with $^3/_4$ in. [20 mm] minimum to $1^1/_8$ in. [30 mm] maximum dimensions shall be used for straight-beam scanning (see 7.2); and search units equipped from $^1/_2$ by 1 in. [13 by 25 mm] to 1 by 1 in. [25 by 25 mm] shall be used for angle-beam scanning (see 7.3).

4.2.1 *Transducers* shall be utilized at their rated frequencies.

4.2.2 Other search units may be used for evaluating and pinpointing indications.

4.3 *Couplants* having good wetting characteristics such as SAE No. 20 or No. 30 motor oil, glycerin, pine oil, or water shall be used. Couplants may not be comparable to one another and the same couplant shall be used for calibration and examination.

4.4 *Reference Blocks* containing flat-bottom holes may be used for calibration of equipment in accordance with 4.1.1 and may be used to establish recording levels for straight-beam examination when so specified by the order or contract.

4.5 DGS scales, matched to the ultrasonic test unit and transducer to be utilized, may be used to establish recording levels for straight-beam examination, when so specified by the order or contract. The DGS scale range must be selected to include the full thickness cross-section of the forging to be examined. An example of a DGS overlay is found in Appendix X3.

5. Personnel Requirements

5.1 Personnel performing the ultrasonic examinations to this practice shall be qualified and certified in accordance with a written procedure conforming to Recommended Practice No. SNT-TC-1A or another national standard that is acceptable to both the purchaser and the supplier.

6. Preparation of Forging for Ultrasonic Examination

6.1 Unless otherwise specified in the order or contract, the forging shall be machined to provide cylindrical surfaces for radial examination in the case of round forgings; the ends of the forgings shall be machined perpendicular to the axis of the forging for the axial examination. Faces of disk and rectangular forgings shall be machined flat and parallel to one another.

6.2 The surface roughness of exterior finishes shall not exceed 250 μin. [6 μm] unless otherwise shown on the forging drawing or stated in the order or the contract.

6.3 The surfaces of the forging to be examined shall be free of extraneous material such as loose scale, paint, dirt, etc.

7. Procedure

7.1 *General:*

7.1.1 As far as practicable, subject the entire volume of the forging to ultrasonic examination. Because of radii at change of sections and other local configurations, it may be impossible to examine some sections of a forging.

7.1.2 Perform the ultrasonic examination after heat treatment for mechanical properties (exclusive of stress-relief treatments) but prior to drilling holes, cutting keyways, tapers, grooves, or machining sections to contour. If the configuration of the forging required for the treatment for mechanical properties prohibits a subsequent complete examination of the forging, it shall be permissible to examine prior to treatment for

mechanical properties. In such cases, reexamine the forging ultrasonically as completely as possible after heat treatment.

7.1.3 To ensure complete coverage of the forging volume, index the search unit with at least 15% overlap with each pass.

7.1.4 Do not exceed a scanning rate of 6 in./s [150 mm/s].

7.1.5 If possible, scan all sections of forgings in two perpendicular directions.

7.1.6 Scan disk forgings using a straight-beam technique from at least one flat face and radially from the circumference, whenever practicable.

7.1.7 Scan cylindrical sections and hollow forgings by angle-beam technique. When practicable, also examine the forging in the axial direction.

7.1.8 In addition, examine hollow forgings by angle-beam technique from the outside diameter surface as required in 7.3.1.

7.1.9 In rechecking or reevaluation by manufacturer or purchaser use comparable equipment, search units, frequency, and couplant.

7.1.10 Forgings may be examined either stationary or while rotating in a lathe or on rollers. If not specified by the purchaser, either method may be used at the manufacturer's option.

7.2 *Straight-Beam Examination:*

7.2.1 For straight-beam examination use a nominal $2^1/_4$-MHz search unit whenever practicable; however, 1 MHz is the preferred frequency for coarse grained austenitic materials and long testing distances. In many instances on examining coarse grained austenitic materials it may be necessary to use a frequency of 0.4 MHz. Other frequencies may be used if desirable for better resolution, penetrability, or detectability of flaws.

7.2.2 Establish the instrument sensitivity by either the reflection, reference-block technique, or DGS method (see Appendix X3 for an explanation of the DGS method).

7.2.2.1 *Back-Reflection Technique (Back-Reflection Calibration Applicable to Forgings with Parallel Entry and Back Surfaces)* — With the attenuator set at an appropriate level, for example 5 to 1 or 14 dB, adjust the instrument controls to obtain a back reflection approximately 75% of the full-screen height from the opposite side of the forging. Scan the forging at the maximum amplification setting of the attenuator (attenuator set at 1 to 1). Carry out the evaluation of discontinuities with the gain control set at the reference level. Recalibration is required for significant changes in section thickness or diameter.

NOTE 1 — High sensitivity levels are not usually employed when inspecting austenitic steel forgings, due to attendant high level of "noise" or "hash" caused by coarse grain structure.

7.2.2.2 *Reference-Block Calibration* — The test surface roughness on the calibration standard shall be comparable to but no better than the item to be examined. Adjust the instrument controls to obtain the required signal amplitude from the flat-bottom hole in the specified reference block. Utilize the attenuator in order to set up on amplitudes larger than the vertical linearity of the instrument. In those cases, remove the attenuation prior to scanning the forging.

NOTE 2 — When flat-surfaced reference block calibration is specified, adjust the amplitude of indication from the reference block or blocks to compensate for examination surface curvature (an example is given in Appendix X1).

7.2.2.3 *DGS Calibration* — Prior to use, verify that the DGS overlay matches the transducer size and frequency. Accuracy of the overlay can be verified by reference blocks and procedures outlined in Practice E 317. Overlays are to be serialized to match the ultrasonic transducer and pulse-echo testing system that they are to be utilized with.

7.2.2.4 Choose the appropriate DGS scale for the cross-sectional thickness of the forging to be examined. Insert the overlay over the CRT screen, ensuring the DGS scale baseline coincides with the sweep line of the CRT screen. Place the probe on the forging, adjust the gain to make the first backwall echo appear clearly on the CRT screen. Using the Delay and Sweep control, shift the screen pattern so that the leading edge of the initial pulse is on zero of the DGS scale and the backwall echo is on the DGS scale value corresponding to the thickness of the forging. Adjust the gain so the forging backwall echo matches the height of the DGS reference slope within ± 1 Db. Once adjusted, increase the gain by the Db shown on the DGS scale for the reference slope. The instrument is now calibrated and flaw sizes that can be reliably detected can be directly read from the CRT screen. These flaw sizes are the equivalent flat bottom reflector that can be used as a reference point.

NOTE 3 — The above can be utilized on all solid forgings. Cylindrical hollow forgings and drilled or bored forgings must be corrected to compensate for attenuation due to the central hole (see Appendix X4).

7.2.3 *Recalibration* — Any change in the search unit, couplant, instrument setting, or scanning speed from that used for calibration shall require recalibration. Perform a calibration check at least once every 8 h shift. When a loss of 15% or greater in the gain level is indicated, reestablish the required calibration and reexamine all of the material examined in the preceding calibration period. When an increase of 15% or greater in the gain level is indicated, reevaluate all recorded indications.

7.2.4 During the examination of the forging, monitor the back reflection for any significant reduction in amplitude. Reduction in back-reflection amplitude may indicate not only the presence of a discontinuity but also poor coupling of the search unit with the surface of the forging, nonparallel back-reflection surface, or local variations of attenuation in the forging. Recheck any areas causing loss of back reflection.

7.3 *Angle-Beam Examination — Rings and Hollow Forgings:*

7.3.1 Perform the examination from the circumference of rings and hollow forgings that have an axial length greater than 2 in. [50 mm] and an outside to inside diameter ratio of less than 2.0 to 1.

7.3.2 Use a 1 MHz, 45° angle-beam search unit unless thickness, OD/ID ratio, or other geometric configuration results in failure to achieve calibration. Other frequencies may be used if desirable for better resolution, penetrability, or detectability of flaws. For angle-beam inspection of hollow forgings up to 2.0 to 1 ratio, provide the transducer with a wedge or shoe that will result in the beam mode and angle required by the size and shape of the cross section under examination.

7.3.3 Calibrate the instrument for the angle-beam examination to obtain an indication amplitude of approximately 75% full-screen height from a rectangular or a 60° V-notch on inside diameter (ID) in the axial direction and parallel to the axis of the forging. A separate calibration standard may be used; however, it shall have the same nominal composition, heat treatment, and thickness as the forging it represents. The test surface finish on the calibration standard shall be comparable but no better than the item to be examined. Where a group of identical forgings is made, one of these forgings may be used as the separate calibration standard. Cut the ID notch depth to 3% maximum of the thickness or $^1/_4$ in. [6 mm], whichever is smaller, and its length approximately 1 in. [25 mm]. Thickness is defined as the thickness of the forging to be examined at the time of examination. At the same instrument setting, obtain a reflection from a similar OD notch. Draw a line through the peaks of the first reflections obtained from the ID and OD notches. This shall be the amplitude reference line. It is preferable to have the notches in excess metal or test metal when possible. When the OD notch cannot be detected when examining the OD surface, perform the examination when practicable (some IDs may be too small to permit examination) as indicated above from both the OD and ID surfaces. Utilize the ID notch when inspecting from the OD, and the OD notch when inspecting from the ID. Curve wedges or shoes may be used when necessary and practicable.

7.3.4 Perform the examination by scanning over the entire surface area circumferentially in both the clockwise and counter-clockwise directions from the OD surface. Examine forgings, which cannot be examined axially using a straight beam, in both axial directions with an angle-beam search unit. For axial scanning, use rectangular or 60° V-notches on the ID and OD for the calibration. These notches shall be perpendicular to the axis of the forging and the same dimensions as the axial notch.

8. Recording

8.1 *Straight-Beam Examination* — Record the following indications as information for the purchaser. These recordable indications do not constitute a rejectable condition unless negotiated as such in the purchase order.

8.1.1 In the back-reflection technique, individual indications equal to or exceeding 10% of the back reflection from an adjacent area free from indications; in the reference-block or DGS technique, indications equal to or exceeding 100% of the reference amplitude.

8.1.2 An indication that is continuous on the same plane regardless of amplitude, and found over an area larger than twice the diameter of the search unit. The extent of such an indication shall be accurately measured along with variations in amplitudes of reflections.

8.1.2.1 Planar indications shall be considered continuous over a plane if they have a major axis greater than 1 in. [25 mm]. In recording these indications, corrections must be made for beam divergence at the estimated flaw depth.

8.1.3 In the back-reflection technique, discontinuity indications equal to or exceeding 5% of the back reflection. In the reference-block technique, indications

equal to or exceeding 50% of the reference amplitude providing that they travel, are continuous, or appear as clusters.

8.1.3.1 Traveling indications are herein defined as indications whose leading edge moves a distance equivalent to 1 in. [25 mm] or more of metal depth with movement of the search unit over the surface of the forging.

8.1.3.2 A cluster of indications is defined as five or more indications located in a volume representing a 2 in. [50 mm] or smaller cube in the forging.

8.1.4 Reduction in back reflection exceeding 20% of the original measured in increments of 10%.

8.1.5 Amplitudes of recordable indications in increments of 10%.

8.2 *Angle-Beam Examination* — Record discontinuity indications equal to or exceeding 50% of the indication from the reference line. When an amplitude reference line cannot be generated, record discontinuity indications equal to or exceeding 50% of the reference notch. These recordable indications do not constitute a rejectable condition unless negotiated as such in the purchase order.

9. Report

9.1 Report the following information:

9.1.1 All recordable indications (see Section 8).

9.1.2 For the purpose of reporting the locations of recordable indications, a sketch shall be prepared showing the physical outline of the forging including dimensions of all areas not inspected due to geometric configuration, the purchaser's drawing number, the purchaser's order number, and the manufacturer's serial number, and the axial, radial, and circumferential distribution of recordable ultrasonic indications.

9.1.3 The specification to which the examination was performed as well as the frequency used, method of setting sensitivity, type of instrument, surface finish, couplant, and search unit employed.

9.1.4 The inspector's signature and date examination performed.

10. Quality Levels

10.1 This practice is intended for application to forgings, with a wide variety of sizes, shapes, compositions, melting processes, and applications. It is, therefore, impracticable to specify an ultrasonic quality level which would be universally applicable to such a diversity of products. Ultrasonic acceptance or rejection criteria for individual forgings should be based on a realistic appraisal of service requirements and the quality that can normally be obtained in the production of the particular type forging.

10.2 Heavy austenitic stainless steel forgings are more difficult to penetrate ultrasonically than similar carbon or low-alloy steel forgings. The degree of attenuation normally increases with section size; and the noise level, generally or in isolated areas, may become too great to permit detection of discrete indications. In most instances, this attenuation results from inherent coarse grained microstructure of these austenitic alloys. For these reasons, the methods and standards employed for ultrasonically examining carbon and low-alloy steel forgings may not be applicable to heavy austenitic steel forgings. In general, only straight-beam inspecting using a back-reflection reference standard is used. However, utilization of Practice A 745/A 745M for austenitic steel forgings can be considered if flat-bottom hole reference standards or angle-beam examination of these grades are required.

10.3 Acceptance quality levels shall be established between purchaser and manufacturer on the basis of one or more of the following criteria.

10.3.1 *Straight-Beam Examination:*

10.3.1.1 No indications larger than some percentage of the reference back reflection.

10.3.1.2 No indications equal to or larger than the indication received from the flat-bottom hole in a specific reference block or blocks.

10.3.1.3 No areas showing loss of back reflection larger than some percentage of the reference back reflection.

10.3.1.4 No indications per 10.3.1.1 or 10.3.1.2 coupled with some loss of resultant back reflection per 10.3.1.3.

10.3.1.5 No indications exceeding the reference level specified in the DGS method.

10.3.2 *Angle-Beam Examination* — No indications exceeding a stated percentage of the reflection from a reference notch or of the amplitude reference line.

10.4 Intelligent application of ultrasonic quality levels involves an understanding of the effects of many parameters on examination results.

STANDARD TEST METHOD FOR SULFUR IN PETROLEUM PRODUCTS (HIGH-TEMPERATURE METHOD)

SD-1552

(Identical with ASTM D 1552-95)

1. Scope

1.1 This test method covers three procedures for the determination of total sulfur in petroleum products including lubricating oils containing additives, and in additive concentrates. This test method is applicable to samples boiling above 177°C (350°F) and containing not less than 0.06 mass % sulfur. Two of the three procedures use iodate detection; one employing an induction furnace for pyrolysis, the other a resistance furnace. The third procedure uses IR detection following pyrolysis in a resistance furnace.

1.2 Petroleum coke containing up to 8 mass % sulfur can be analyzed.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1193 Specification for Reagent Water

D 1266 Test Method for Sulfur in Petroleum Products (Lamp Method)

D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products

3. Summary of Test Method

3.1 *Iodate Detection System* — The sample is burned in a stream of oxygen at a sufficiently high temperature to convert about 97% of the sulfur to sulfur dioxide. A standardization factor is employed to obtain accurate results. The combustion products are passed into an absorber containing an acid solution of potassium iodide and starch indicator. A faint blue color is developed in the absorber solution by the addition of standard potassium iodate solution. As combustion proceeds, bleaching the blue color, more iodate is added. The amount of standard iodate consumed during the combustion is a measure of the sulfur content of the sample.

3.2 *IR Detection System* — The sample is weighed into a special ceramic boat which is then placed into a combustion furnace at 1371°C (2500°F) in an oxygen atmosphere. Most sulfur present is combusted to SO_2 which is then measured with an infrared detector after moisture and dust are removed by traps. A microprocessor calculates the mass percent sulfur from the sample weight, the integrated detector signal, and a predetermined calibration factor. Both the sample identification number and mass percent sulfur are then printed out. The calibration factor is determined using standards approximating the material to be analyzed.

4. Significance and Use

4.1 This test method provides a means of monitoring the sulfur level of various petroleum products and additives. This knowledge can be used to predict performance, handling, or processing properties. In some cases the presence of sulfur compounds is beneficial

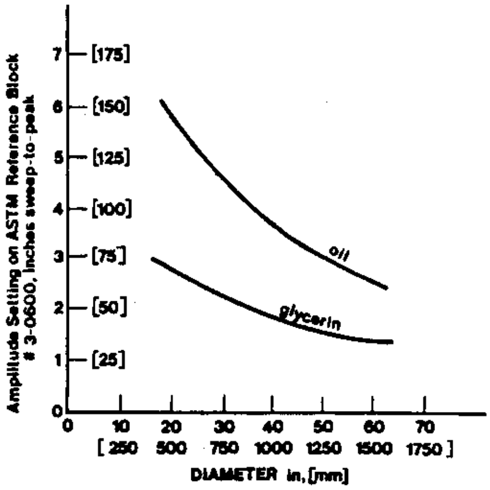


FIG. X1.1 TYPICAL COMPENSATION CURVE FOR EFFECTS OF FORGING CURVATURE

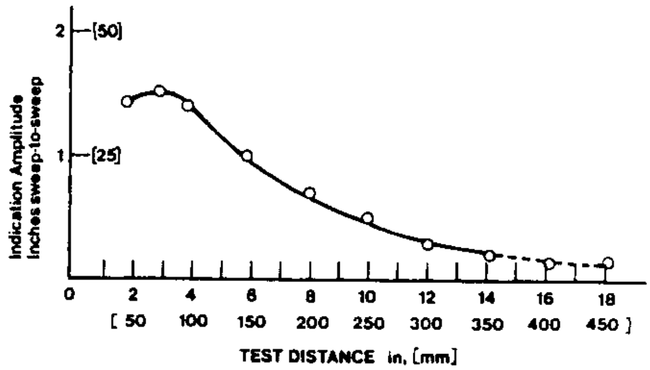


FIG. X2.1 TYPICAL DISTANCE-AMPLITUDE CORRECTION CURVE

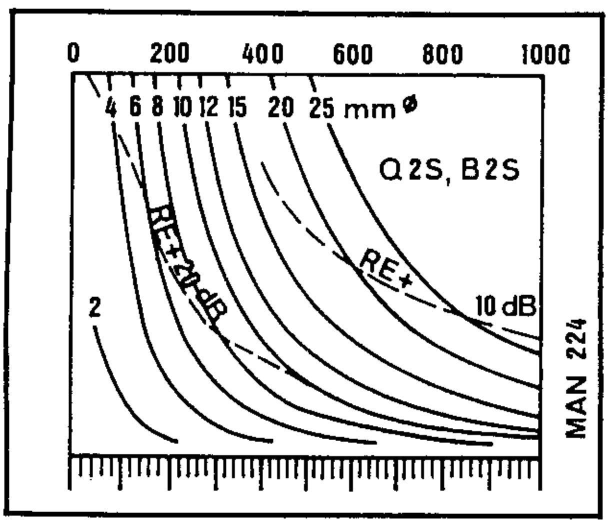
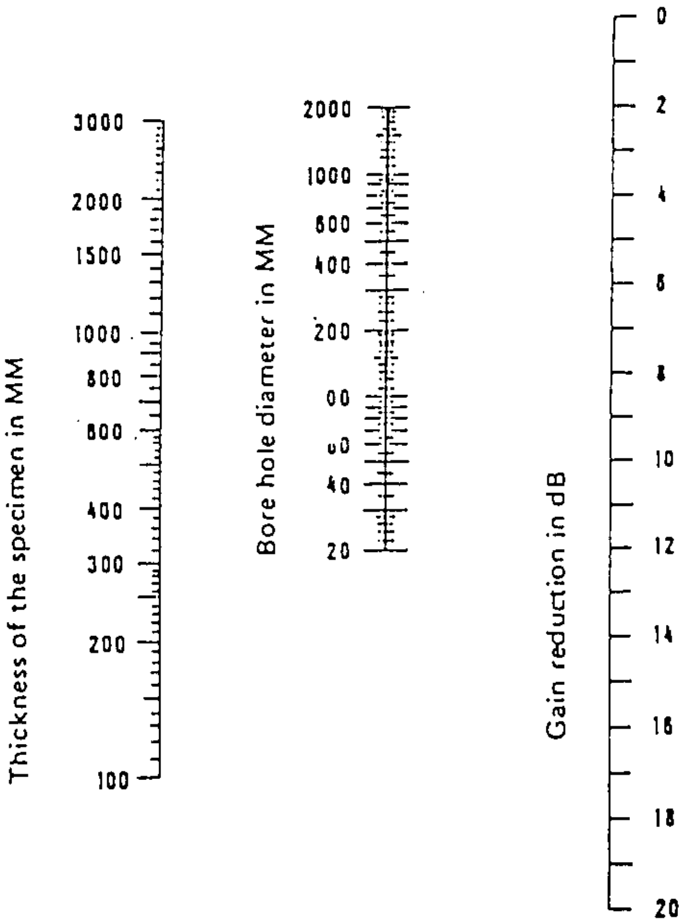


FIG. X4.1 EXAMPLE OF DGS OVERLAY



NOTE—Metric units are presented in this figure to be consistent with DGS scales presently available. Conversion to English units would also be acceptable.

FIG. X4.2 THE INFLUENCE OF A CENTRAL BORE ON THE BACKWALL ECHO AMPLITUDE OF CYLINDRICAL OR PLANE PARALLEL FORGINGS

STANDARD SPECIFICATION FOR STRAIGHT-BEAM ULTRASONIC EXAMINATION OF STEEL PLATES

SA-435/SA-435M

[Identical with ASTM Specification A 435/A 435M-90 (1996)]

1. Scope

1.1 This specification covers the procedure and acceptance standards for straight-beam, pulse-echo, ultrasonic examination of rolled fully killed carbon and alloy steel plates, $\frac{1}{2}$ in. [12.5 mm] and over in thickness. It was developed to assure delivery of steel plates free of gross internal discontinuities such as pipe, ruptures, or laminations, and is to be used whenever the inquiry, contract, order, or specification states that the plates are to be subjected to ultrasonic examination.

1.2 Individuals performing examinations in accordance with this specification shall be qualified and certified in accordance with the requirements of the latest edition of ASNT SNT-TC-1A or an equivalent accepted standard. An equivalent standard is one which covers the qualification and certification of ultrasonic nondestructive examination candidates and which is acceptable to the purchaser.

1.3 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents, therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Document

2.1 *ASNT Standard:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

3. Apparatus

3.1 The manufacturer shall furnish suitable ultrasonic equipment and qualified personnel necessary for performing the test. The equipment shall be of the pulse-echo straight-beam type. The transducer is normally 1 to $1\frac{1}{8}$ in. [25 to 30 mm] in diameter or 1 in [25 mm] square; however, any transducer having a minimum active area of 0.7 in.^{2} [450 mm^2] may be used. The test shall be performed by one of the following methods: direct contact, immersion, or liquid column coupling.

3.2 Other search units may be used for evaluating and pinpointing indications.

4. Test Conditions

4.1 Conduct the examination in an area free of operations that interfere with proper functioning of the equipment.

4.2 Clean and smooth the plate surface sufficiently to maintain a reference back reflection from the opposite side of the plate at least 50% of the full scale during scanning.

4.3 The surface of plates inspected by this method may be expected to contain a residue of oil or rust or both. Any specified identification which is removed when grinding to achieve proper surface smoothness shall be restored.

5. Procedure

5.1 Ultrasonic examination shall be made on either major surface of the plate. Acceptance of defects in

close proximity may require inspection from the second major surface. Plates ordered in the quenched and tempered condition shall be tested following heat treatment.

5.2 A nominal test frequency of $2\frac{1}{4}$ MHz is recommended. Thickness, grain size, or microstructure of the material and nature of the equipment or method may require a higher or lower test frequency. However, frequencies less than 1 MHz may be used only on agreement with the purchaser. A clear, easily interpreted trace pattern should be produced during the examination.

5.3 Conduct the examination with a test frequency and instrument adjustment that will produce a minimum 50 to a maximum 75% of full scale reference back reflection from the opposite side of a sound area of the plate. While calibrating the instrument, sweep the crystal along the plate surface for a distance of at least 1*T* or 6 in. [150 mm], whichever is the greater, and note the position of the back reflection. A shift in location of the back reflection during calibration shall be cause for recalibration of the instrument.

5.4 Scanning shall be continuous along perpendicular grid lines on nominal 9-in. [225-mm] centers, or at the manufacturer's option, shall be continuous along parallel paths, transverse to the major plate axis, on nominal 4-in. [100-mm] centers, or shall be continuous along parallel paths parallel to the major plate axis, on 3-in [75-mm] or smaller centers. A suitable couplant such as water, soluble oil, or glycerin, shall be used.

5.5 Scanning lines shall be measured from the center or one corner of the plate. An additional path shall be scanned within 2 in. [50 mm] of all edges of the plate on the scanning surface.

5.6 Where grid scanning is performed and complete loss of back reflection accompanied by continuous indications is detected along a given grid line, the entire surface area of the squares adjacent to this indication shall be scanned continuously. Where parallel path scanning is performed and complete loss of back reflection accompanied by continuous indications is detected, the entire surface area of a 9 by 9-in. [225 by 225-mm] square centered on this indication shall be scanned continuously. The true boundaries where this condition exists shall be established in either method by the following technique: Move the transducer away from the center of the discontinuity until the heights of the back reflection and discontinuity indications are equal. Mark the plate at a point equivalent to the center of the transducer. Repeat the operation to establish the boundary.

6. Acceptance Standards

6.1 Any discontinuity indication causing a total loss of back reflection which cannot be contained within a circle, the diameter of which is 3 in. [75 mm] or one half of the plate thickness, whichever is greater, is unacceptable.

6.2 The manufacturer reserves the right to discuss rejectable ultrasonically tested plates with the purchaser with the object of possible repair of the ultrasonically indicated defect before rejection of the plate.

6.3 The purchaser's representative may witness the test.

7. Marking

7.1 Plates accepted in accordance with this specification shall be identified by stamping or stenciling UT 435 adjacent to marking required by the material specification.

SUPPLEMENTARY REQUIREMENTS

The following shall apply only if specified in the order:

S1.

Instead of the scanning procedure specified by 5.4 and 5.5, and as agreed upon between manufacturer and purchaser, 100% of one major plate surface shall be scanned. Scanning shall be continuous along parallel paths, transverse or parallel to the major plate axis, with not less than 10% overlap between each path.

STANDARD SPECIFICATION FOR ULTRASONIC ANGLE-BEAM EXAMINATION OF STEEL PLATES

SA-577/SA-577M

[Identical with ASTM Specification A 577/A 577M-90 (1996)]

1. Scope

1.1 This specification covers an ultrasonic angle-beam procedure and acceptance standards for the detection of internal discontinuities not laminar in nature and of surface imperfections in a steel plate. This specification is intended for use only as a supplement to specifications which provide straight-beam ultrasonic examination.

NOTE — An internal discontinuity that is laminar in nature is one whose principal plane is parallel to the principal plane of the plate.

1.2 Individuals performing examinations in accordance with this specification shall be qualified and certified in accordance with the requirements of the latest edition of ASNT SNT-TC-1A or an equivalent accepted standard. An equivalent standard is one which covers the qualification and certification of ultrasonic nondestructive examination candidates and which is acceptable to the purchaser.

1.3 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Document

2.1 *ASNT Standard:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

3. Ordering Information

3.1 The inquiry and order shall indicate any additions to the provisions of this specification as prescribed in 14.1.

4. Examination Conditions

4.1 The examination shall be conducted in an area free of operations that interfere with proper performance of the examination.

4.2 The surface of the plate shall be conditioned as necessary to provide a clear, easily interpreted trace pattern on the screen. Any specified identification which is removed to achieve proper surface smoothness shall be restored.

5. Apparatus

5.1 The amplitude linearity shall be checked by positioning the transducer over the depth resolution notch in the IIW or similar block so that the signal from the notch is approximately 30% of the screen height, and the signal from one of the back surfaces is approximately 60% of the screen height (two times the height of the signal from the notch). A curve is then plotted showing the deviations from the above established 2:1 ratio that occurs as the amplitude of the signal from the notch is raised in increments of one scale division until the back reflection signal reaches full scale, and then is lowered in increments of one scale division until the notch signal reaches one scale division. At each increment the ratio of the two signals is determined. The ratios are plotted on the graph at the position corresponding to the larger signal. Between the limits of 20% and 80% of the screen height the

ratio shall be within 10% of 2:1. Instrument settings used during inspection shall not cause variation outside the 10% limits established above.

5.2 The search unit shall be a 45-deg (in steel) angle-beam type with active transducer length and width dimensions of a minimum of $\frac{1}{2}$ in. [12.5 mm] and a maximum of 1 in. [25 mm]. Search units of other sizes and angles may be used for additional exploration and evaluation.

6. Examination Frequency

6.1 The ultrasonic frequency selected for the examination shall be the highest frequency that permits detection of the required calibration notch, such that the amplitude of the indication yields a signal-to-noise ratio of at least 3:1.

7. Calibration Reflector

7.1 A calibration notch, the geometry of which has been agreed upon by the purchaser and the manufacturer, with a depth of 3% of the plate thickness, shall be used to calibrate the ultrasonic examination. The notch shall be at least 1 in. [25 mm] long.

7.2 Insert the notch or notches on the surface of the plate so that they are perpendicular to the long axis at a distance of 2 in. [50 mm] or more from the short edge of the plate. Locate the notch not less than 2 in. [50 mm] from the long edges of the plate.

7.3 When the notch cannot be inserted in the plate to be tested, it may be placed in a calibration plate of ultrasonically similar material. The calibration plate will be considered ultrasonically similar if the height of the first back reflection through it is within 25% of that through the plate to be tested at the same instrument calibration. The calibration plate thickness shall be within 1 in. [25 mm] of the thickness of plates to be tested, for plates of 2 in. [50 mm] thickness and greater and within 10% of plates whose thickness is less than 2 in. [50 mm].

7.4 For plate thicknesses greater than 2 in. [50 mm], insert a second calibration notch as described in 7.2, on the opposite side of the plate.

8. Calibration Procedure

8.1 *Plate 2 in.* [50 mm] *and Under in Thickness:*

8.1.1 Place the search unit on the notched surface of the plate with the sound beam directed at the broad side of the notch and position to obtain maximum amplitude from the first vee-path indication which is clearly resolved from the initial pulse. Adjust the instrument gain so that this reflection amplitude is at least 50 but not more than 75% of full screen height. Record the location and amplitude of this indication on the screen.

8.1.2 Move the search unit away from the notch until the second vee-path indication is obtained. Position the search unit for maximum amplitude and record the indication amplitude. Draw a line between the peaks from the two successive notch indications on the screen. This line is the distance amplitude curve (DAC) for this material and shall be a 100% reference line for reporting indication amplitudes.

8.2 *Plate Over 2 to 6 in.* [50 to 150 mm] *Inclusive in Thickness:*

8.2.1 Place the search unit on the test surface aimed at the broad side of the notch on the opposite surface of the plate. Position the search unit to obtain a maximum one-half vee-path indication amplitude. Adjust the instrument gain so that this amplitude is at least 50% but not more than 80% of full screen height. Record the location and amplitude on the screen. Without adjusting the instrument settings, repeat this procedure for the $1\frac{1}{2}$ vee-path indication.

8.2.2 Without adjusting the instrument settings, reposition the search unit to obtain a maximum full vee-path indication from the notch on the test surface. Record the location and amplitude on the screen.

8.2.3 Draw a line on the screen connecting the points established in 8.2.1 and 8.2.2. This curve shall be a DAC for reporting indication amplitudes.

8.3 *Plate Over 6 in.* [150 mm] *in Thickness:*

8.3.1 Place the search unit on the test surface aimed at the broad side of the notch on the opposite surface of the plate. Position the search unit to obtain a maximum one-half vee-path indication amplitude. Adjust the instrument gain so that this amplitude is at least 50% but not more than 80% of full screen height. Record the location and amplitude on the screen.

8.3.2 Without adjusting the instrument settings, reposition the search unit to obtain a maximum full

vee-path indication from the notch on the test surface. Record the location and amplitude on the screen.

8.3.3 Draw a line on the screen connecting the points established in 8.3.1 and 8.3.2. This line shall be a DAC for reporting indication amplitudes.

9. Examination Procedure

9.1 Scan one major surface of the plate on grid lines perpendicular and parallel to the major rolling direction. Grid lines shall be on 9-in. [225-mm] centers. Use a suitable couplant such as water, oil, or glycerin. Scan by placing the search unit near one edge with the ultrasonic beam directed toward the same edge and move the search unit along the grid line in a direction perpendicular to the edge to a location two plate thicknesses beyond the plate center. Repeat this scanning procedure on all grid lines from each of the four edges.

9.2 Measure grid lines from the center or one corner of the plate.

9.3 Position the search unit to obtain a maximum indication amplitude from each observed discontinuity.

9.4 For each discontinuity indication that equals or exceeds the DAC, record the location and length, and the amplitude to the nearest 25%. No indication with an amplitude less than the DAC shall be recorded.

9.5 At each recorded discontinuity location, conduct a 100% examination of the mass under a 9-in. [225-mm] square which has the recorded discontinuity position at its center. Conduct the examination in directions perpendicular and parallel to the major rolling direction.

10. Acceptance Standard

10.1 Any discontinuity indication that equals or exceeds the DAC shall be considered unacceptable unless additional exploration by the longitudinal method indicates it is laminar in nature.

11. Rehearing

11.1 The manufacturer reserves the right to discuss unacceptable ultrasonically examined plate with the purchaser with the object of possible repair of the ultrasonically indicated discontinuity before rejection of the plate.

12. Inspection

12.1 The purchaser's representative shall have access, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the ultrasonic examination of the material ordered. The manufacturer shall afford the representative all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All examinations and verifications shall be so conducted as not to interfere unnecessarily with the manufacturer's operations.

13. Marking

13.1 Plates accepted in accordance with this specification shall be identified by metal stamping or stencilling "UT A 577" in one corner of the plate, at a location within 6 in. [150 mm] of the heat number.

14. Report

14.1 Unless otherwise agreed upon between the purchaser and manufacturer, the manufacturer shall report the following data:

14.1.1 Plate identity including pin-pointed recordable indication locations, lengths, and amplitudes.

14.1.2 Examination parameters, including: couplant; search unit type, angle, frequency, and size; instrument make, model, and serial number; and calibration plate description.

14.1.3 Date of examination and name of operator.

STANDARD SPECIFICATION FOR STRAIGHT-BEAM ULTRASONIC EXAMINATION OF PLAIN AND CLAD STEEL PLATES FOR SPECIAL APPLICATIONS

SA-578/SA-578M

(Identical with ASTM Specification A 578/A 578M-96)

1. Scope

1.1 This specification covers the procedure and acceptance standards for straight-beam, pulse-echo, ultrasonic examination of rolled carbon and alloy plain and clad steel plates, $^3/_8$ in. [10 mm] in thickness and over, for special applications. The method will detect internal discontinuities parallel to the rolled surfaces. Three levels of acceptance standards are provided. Supplementary requirements are provided for examination of clad plate and for alternative procedures.

1.2 Individuals performing examinations in accordance with this specification shall be qualified and certified in accordance with the requirements of the latest edition of ASNT SNT-TC-1A or an equivalent accepted standard. An equivalent standard is one which covers the qualification and certification of ultrasonic nondestructive examination candidates and which is acceptable to the purchaser.

1.3 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 263 Specification for Corrosion-Resisting Chromium Steel–Clad Plate, Sheet, and Strip

A 264 Specification for Stainless Chromium-Nickel Steel–Clad Plate, Sheet, and Strip

A 265 Specification for Nickel and Nickel-Base Alloy–Clad Steel Plate

2.2 *ANSI Standard:*

B 46.1 Surface Texture

2.3 *ASNT Standard:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

3. Ordering Information

3.1 The inquiry and order shall indicate the following:

3.1.1 Acceptance level requirements (Sections 7, 8, and 9). Acceptance Level B shall apply unless otherwise agreed to by purchaser and manufacturer.

3.1.2 Any additions to the provisions of this specification as prescribed in 5.2, 12.1, and Section 13.

3.1.3 Supplementary requirements, if any.

4. Apparatus

4.1 The amplitude linearity shall be checked by positioning the transducer over the depth resolution notch in the IIW or similar block so that the signal from the notch is approximately 30% of the screen height, and the signal from one of the back surfaces

is approximately 60% of the screen height (two times the height of the signal from the notch). A curve is then plotted showing the deviations from the above established 2:1 ratio that occurs as the amplitude of the signal from the notch is raised in increments of one scale division until the back reflection signal reaches full scale, and then is lowered in increments of one scale division until the notch signal reaches one scale division. At each increment the ratio of the two signals is determined. The ratios are plotted on the graph at the position corresponding to the larger signal. Between the limits of 20% and 80% of the screen height, the ratio shall be within 10% of 2:1. Instrument settings used during inspection shall not cause variation outside the 10% limits established above.

4.2 The transducer shall be 1 or $1\frac{1}{8}$ in. [25 or 30 mm] in diameter or 1 in. [25 mm] square.

4.3 Other search units may be used for evaluating and pinpointing indications.

5. Procedure

5.1 Perform the inspection in an area free of operations that interfere with proper performance of the test.

5.2 Unless otherwise specified, make the ultrasonic examination on either major surface of the plate.

5.3 The plate surface shall be sufficiently clean and smooth to maintain a first reflection from the opposite side of the plate at least 50% of full scale during scanning. This may involve suitable means of scale removal at the manufacturer's option. Condition local rough surfaces by grinding. Restore any specified identification which is removed when grinding to achieve proper surface smoothness.

5.4 Perform the test by one of the following methods: direct contact, immersion, or liquid column coupling. Use a suitable couplant such as water, soluble oil, or glycerin. As a result of the test by this method, the surface of plates may be expected to have a residue of oil or rust, or both.

5.5 A nominal test frequency of $2\frac{1}{4}$ MHz is recommended. When testing plates less than $\frac{3}{4}$ in. [20 mm] thick, a frequency of 5 MHz may be necessary. Thickness, grain size or microstructure of the material and nature of the equipment or method may require a higher or lower test frequency. Use the transducers at their rated frequency. A clean, easily interpreted trace pattern should be produced during the examination.

5.6 *Scanning:*

5.6.1 Scanning shall be along continuous perpendicular grid lines on nominal 9-in. [225-mm] centers, or at the option of the manufacturer, shall be along continuous parallel paths, transverse to the major plate axis, on nominal 4-in. [100-mm] centers, or shall be along continuous parallel paths parallel to the major plate axis, on 3-in. [75-mm] or smaller centers. Measure the lines from the center or one corner of the plate with an additional path within 2 in. [50 mm] of all edges of the plate on the searching surface.

5.6.2 Conduct the general scanning with an instrument adjustment that will produce a first reflection from the opposite side of a sound area of the plate from 50% to 90% of full scale. Minor sensitivity adjustments may be made to accommodate for surface roughness.

5.6.3 When a discontinuity condition is observed during general scanning, adjust the instrument to produce a first reflection from the opposite side of a sound area of the plate of 75 ± 5% of full scale. Maintain this instrument setting during evaluation of the discontinuity condition.

6. Recording

6.1 Record all discontinuities causing complete loss of back reflection.

6.2 For plates $\frac{3}{4}$ in. [20 mm] thick and over, record all indications with amplitudes equal to or greater than 50% of the initial back reflection and accompanied by a 50% loss of back reflection.

NOTE 2 — Indications occurring midway between the initial pulse and the first back reflection may cause a second reflection at the location of the first back reflection. When this condition is observed it shall be investigated additionally by use of multiple back reflections.

6.3 Where grid scanning is performed and recordable conditions as in 6.1 and 6.2 are detected along a given grid line, the entire surface area of the squares adjacent to this indication shall be scanned. Where parallel path scanning is performed and recordable conditions as in 6.1 and 6.2 are detected, the entire surface area of a 9 by 9-in. [225 by 225-mm] square centered on this indication shall be scanned. The true boundaries where these conditions exist shall be established in either method by the following technique: Move the transducer away from the center of the discontinuity until the height of the back reflection and discontinuity indications are equal. Mark the plate at a point equivalent to the center

of the transducer. Repeat the operation to establish the boundary.

7. Acceptance Standard — Level A

7.1 Any area where one or more discontinuities produce a continuous total loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed within a circle whose diameter is 3 in. [75 mm] or $\frac{1}{2}$ of the plate thickness, whichever is greater, is unacceptable.

8. Acceptance Standards — Level B

8.1 Any area where one or more discontinuities produce a continuous total loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed within a circle whose diameter is 3 in. [75 mm] or $\frac{1}{2}$ of the plate thickness, whichever is greater, is unacceptable.

8.2 In addition, two or more discontinuities smaller than described in 8.1 shall be unacceptable unless separated by a minimum distance equal to the greatest diameter of the larger discontinuity or unless they may be collectively encompassed by the circle described in 8.1.

9. Acceptance Standard — Level C

9.1 Any area where one or more discontinuities produce a continuous total loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed within a 1-in. [25-mm diameter circle is unacceptable.

10. Rehearing

10.1 The manufacturer reserves the right to discuss rejectable ultrasonically tested plate with the purchaser with the object of possible repair of the ultrasonically indicated defect before rejection of the plate.

11. Inspection

11.1 The inspector representing the purchaser shall have access at all times, while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the ultrasonic testing of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests and inspections shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be conducted without interfering unnecessarily with the manufacturer's operations.

12. Marking

12.1 Plates accepted according to this specification shall be identified by stenciling (stamping) "UT A 578 — A" on one corner for Level A, "UT A 578 — B" for Level B, and "UT A 578 — C" for Level C. The supplement number shall be added for each supplementary requirement ordered.

13. Report

13.1 Unless otherwise agreed to by the purchaser and the manufacturer, the manufacturer shall report the following data:

13.1.1 All recordable indications listed in Section 6 on a sketch of the plate with sufficient data to relate the geometry and identity of the sketch to those of the plate.

13.1.2 Test parameters including: Make and model of instrument, test frequency, surface condition, transducer (type and frequency), and couplant.

13.1.3 Date of test.

14. Keywords

14.1 nondestructive testing; pressure containing parts; pressure vessel steels; steel plate for pressure vessel applications; steel plates; ultrasonic examinations

SUPPLEMENTARY REQUIREMENTS

These supplementary requirements shall apply only when individually specified by the purchaser. When details of these requirements are not covered herein, they are subject to agreement between the manufacturer and the purchaser.

S1. Scanning

S1.1 Scanning shall be continuous over 100% of the plate surface.

S2. Acceptance Standard

S2.1 Any recordable condition listed in Section 6 that (1) is continuous, (2) is on the same plane (within 5% of the plate thickness), and (3) cannot be encompassed by a 3-in. [75-mm] diameter circle, is unacceptable. Two or more recordable conditions (see Section 5), that (1) are on the same plane (within 5% of plate thickness), (2) individually can be encompassed by a 3-in. [75-mm] diameter circle, (3) are separated from each other by a distance less than the greatest dimension of the smaller indication, and (4) collectively cannot be encompassed by a 3-in. [75-mm] diameter circle, are unacceptable.

S2.2 An acceptance level more restrictive than Section 7 or 8 shall be used by agreement between the manufacturer and purchaser.

S3. Procedure

S3.1 The manufacturer shall provide a written procedure in accordance with this specification.

S4. Certification

S4.1 The manufacturer shall provide a written certification of the ultrasonic test operator's qualifications.

S5. Surface Finish

S5.1 The surface finish of the plate shall be conditioned to a maximum 125 μin. [3 μm] AA (see ANSI B46.1) prior to test.

S6. Examination of Integrally Bonded Clad Plate, Acceptance Level S6

S6.1 Examine the plate from the clad surface using procedures and techniques in accordance with this specification.

S6.2 Inspect the backing steel to Level B, or, if specifically requested by customer, to Level A or Level C.

S6.3 The cladding shall be interpreted to be unbonded when there is complete loss of back reflection accompanied by an echo indication from the plane of the interface of the clad and backing steel.

S6.4 Unless otherwise specified, indications of unbond determined in accordance with S6.3 that cannot be encompassed within a 3-in. [75-mm] diameter circle shall be weld repaired subject to the requirements and limitations for the repair of defects in cladding of the appropriate material specification.

S6.5 This supplementary requirement is applicable to Specifications A 263, A 264, and A 265.

S7. Examination of Integrally Bonded Clad Plate, Acceptance Level S7

S7.1 The plate shall be examined from the clad surface using procedures and techniques according to this specification except 100% surface search is mandatory.

S7.2 Inspect the backing steel to Level B, or, if specifically requested by customer, to Level A or Level C.

S7.3 The cladding shall be interpreted to be unbonded when there is complete loss of back reflection accompanied by an echo indication from the plane of the interface of the clad and backing steel.

S7.4 Unless otherwise specified, indications of unbond determined in accordance with S7.3 that cannot be encompassed within a 1-in. [25-mm] diameter circle shall be weld repaired subject to the requirements and

TABLE S8.1
CALIBRATION HOLE DIAMETER AS A FUNCTION OF PLATE THICKNESS (S8)

Plate Thickness, in. [mm]	4–6 [100–150]	> 6–9 [> 150–225]	> 9–12 [> 225–300]	> 12–20 [> 300–500]
Hole Diameter, in. [mm]	$\frac{5}{8}$ [16]	$\frac{3}{4}$ [19]	$\frac{7}{8}$ [22]	$1\frac{1}{8}$ [29]

limitations for the repair of defects in cladding of the appropriate material specification. Additionally, prior approval must be obtained if the weld repaired surface exceeds 1.5% of the cladding surface.

S7.5 This supplementary requirement is applicable to Specifications A 263, A 264, and A 265.

S8. Ultrasonic Examination Using Flat Bottom Hole Calibration (for Plates 4 in. [100 mm] Thick and Greater)

S8.1 Use the following calibration and recording procedures in place of 5.6.2, 5.6.3, and Section 6.

S8.2 The transducer shall be in accordance with 4.2.

S8.3 *Reference Reflectors* — The *T*/4, *T*/2, and 3*T*/4 deep flat bottom holes shall be used to calibrate the equipment. The flat bottom hole diameter shall be in accordance with Table S8.1. The holes may be drilled in the plate to be examined if they can be located without interfering with the use of the plate, in a prolongation of the plate to be examined, or in a reference block of the same nominal composition, and thermal treatment as the plate to be examined. The surface of the reference block shall be no better to the unaided eye than the plate surface to be examined. The reference block shall be of the same nominal thickness (within 75 to 125% or 1 in. [25 mm] of the examined plate, whichever is less) and shall have acoustical properties similar to the examined plate. Acoustical similarity is presumed when, without a change in instrument setting, comparison of the back reflection signals between the reference block and the examined plate shows a variation of 25% or less.

S8.4 *Calibration Procedure:*

S8.4.1 Couple and position the search unit for maximum amplitudes from the reflectors at *T*/4, *T*/2, and 3*T*/4. Set the instrument to produce a 75 ± 5% of full scale indication from the reflector giving the highest amplitude.

S8.4.2 Without changing the instrument setting, couple and position the search unit over each of the holes and mark on the screen the maximum amplitude from each hole and each minimum remaining back reflection.

S8.4.3 Mark on the screen half the vertical distance from the sweep line to each maximum amplitude hole mark. Connect the maximum amplitude hole marks and extend the line through the thickness for the 100% DAC (distance–amplitude correction curve). Similarly connect and extend the half maximum amplitude marks for the 50% DAC.

S8.5 *Recording:*

S8.5.1 Record all areas where the remaining back reflection is smaller than the highest of the minimum remaining back reflections found in S8.4.2.

S8.5.2 Record all areas where indications exceed 50% DAC.

S8.5.3 Where recordable conditions listed in S8.5.1 and S8.5.2 are detected along a given grid line, continuously scan the entire surface area of the squares adjacent to the condition and record the boundaries or extent of each recordable condition.

S8.6 Scanning shall be in accordance with 5.6.

S8.7 The acceptance levels of Section 7 or 8 shall apply as specified by the purchaser except that the recordable condition shall be as given in S8.5.

S9. Ultrasonic Examination of Electroslag Remelted (ESR) and Vacuum-Arc Remelted (VAR) Plates, from 1 to 16 in. [25 to 400 mm] in Thickness, Using Flat-Bottom Hole Calibration and Distance–Amplitude Corrections

S9.1 The material to be examined must have a surface finish of 200 μin. [5 μm] as maximum for plates up to 8 in. [200 mm] thick, inclusive, and 250 μin. [6 μm] as maximum for plates over 8 to 16 in. [200 to 400 mm] thick.

S9.2 Use the following procedures in place of 5.6.1, 5.6.2, 5.6.3, and Section 6.

TABLE S9.1
CALIBRATION HOLE DIAMETER AS A FUNCTION OF PLATE THICKNESS (S9)

Plate Thickness, in. [mm]	1–4 [25–100]	> 4–8 [> 100–200]	> 8–12 [> 200–300]	> 12–16 [> 300–400]
Hole Diameter, in. [mm]	$\frac{1}{8}$ [3]	$\frac{1}{4}$ [6]	$\frac{3}{8}$ [10]	$\frac{1}{2}$ [13]

S9.3 The transducer shall be in accordance with 4.2.

S9.4 *Reference Reflectors* — The *T*/4, *T*/2, and 3*T*/4 deep flat bottom holes shall be used to calibrate the equipment. The flat bottom hole diameter shall be in accordance with Table S9.1. The flat bottoms of the holes shall be within 1° of parallel to the examination surface. The holes may be drilled in the plate to be examined if they can be located without interfering with the use of the plate, in a prolongation of the plate to be examined, or in a reference block of the same nominal composition and thermal treatment as the plate to be examined. The surface of the reference block shall be no better to the unaided eye than the plate surface to be examined. The reference block shall be of the same nominal thickness (within 75 to 125% or 1 in. [25 mm] of the examined plate, whichever is less) and shall have acoustical properties similar to the examined plate. Acoustical similarity is presumed when, without a change in instrument setting, comparison of the back reflection signals between the reference block and the examined plate shows a variation of 25% or less.

S9.5 *Calibration Procedure:*

S9.5.1 Couple and position the search unit for maximum amplitudes from the reflectors at *T*/4, *T*/2, and 3*T*/4. Set the instrument to produce a 75 ± 5% of full-scale indication from the reflector giving the highest amplitude.

S9.5.2 Without changing the instrument setting, couple and position the search unit over each of the holes and mark on the screen the maximum amplitude from each of the holes.

S9.5.3 Mark on the screen half the vertical distances from the sweep line to each maximum amplitude hole mark. Connect the maximum amplitude hole marks and extend the line through the thickness for the 100% DAC (distance–amplitude correction curve). Similarly connect and extend the half maximum amplitude marks for the 50% DAC.

S9.6 *Scanning* — Scanning shall cover 100% of one major plate surface, with the search unit being indexed between each pass such that there is at least 15% overlap of adjoining passes in order to assure adequate coverage for locating discontinuities.

S9.7 *Recording* — Record all areas where the back reflection drops below the 50% DAC. If the drop in back reflection is not accompanied by other indications on the screen, recondition the surface in the area and reexamine ultrasonically. If the back reflection is still below 50% DAC, the loss may be due to the metallurgical structure of the material being examined. The material shall be held for metallurgical review by the purchaser and manufacturer.

S9.8 *Acceptance Standards* — Any indication that exceeds the 100% DAC shall be considered unacceptable. The manufacturer may reserve the right to discuss rejectable ultrasonically examined material with the purchaser, the object being the possible repair of the ultrasonically indicated defect before rejection of the plate.

STANDARD PRACTICE FOR CASTINGS, CARBON, LOW-ALLOY, AND MARTENSITIC STAINLESS STEEL, ULTRASONIC EXAMINATION THEREOF

SA-609/SA-609M

[Identical with ASTM Specification A 609/A 609M-91 (1997)]

1. Scope

1.1 This practice covers the standards and procedures for the pulse-echo ultrasonic examination of heat-treated carbon, low-alloy, and martensitic stainless steel castings by the longitudinal-beam technique.

1.2 This practice is to be used whenever the inquiry, contract, order, or specification states that castings are to be subjected to ultrasonic examination in accordance with Practice A 609/A 609M.

1.3 This practice contains two procedures for ultrasonic inspection of carbon, low-alloy, and martensitic stainless steel castings, that is, Procedure A and Procedure B. Procedure A is the original A 609/A 609M practice and requires calibration using a series of test blocks containing flat bottomed holes. It also provides supplementary requirements for angle beam testing. Procedure B requires calibration using a back wall reflection from a series of solid calibration blocks.

NOTE 1 — Ultrasonic examination and radiography are not directly comparable. This examination technique is intended to complement Guide E 94 in the detection of discontinuities.

1.4 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with this practice.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 217/A 217M Specification for Steel Castings, Martensitic Stainless and Alloy, for Pressure-Containing Parts, Suitable for High-Temperature Service

E 94 Guide for Radiographic Testing

E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems Without the Use of Electronic Measurement Instruments

2.2 *Other Document:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification

3. Ordering Information

3.1 The inquiry and order should specify which procedure is to be used. If a procedure is not specified, Procedure A shall be used.

3.2 *Procedure A — Flat-Bottomed Hole Calibration Procedure:*

3.2.1 When this practice is to be applied to an inquiry, contract, or order, the purchaser shall furnish the following information:

3.2.1.1 Quality levels for the entire casting or portions thereof,

3.2.1.2 Sections of castings requiring longitudinal-beam examination,

3.2.1.3 Sections of castings requiring dual element examination,

3.2.1.4 Sections of castings requiring supplementary examination, using the angle-beam procedure described in Supplementary Requirement S1 in order to achieve more complete examination, and

3.2.1.5 Any requirements additional to the provisions of this practice.

3.3 *Procedure B: Back-Wall Reflection Calibration Procedure* — When this procedure is to be applied to an inquiry, contract, or order, the purchaser shall designate the quality levels for the entire casting or applicable portions.

PROCEDURE A — FLAT-BOTTOMED HOLE CALIBRATION PROCEDURE

4. Apparatus

4.1 *Electronic Apparatus:*

4.1.1 An ultrasonic, pulsed, reflection type of instrument that is capable of generating, receiving, and amplifying frequencies of at least 1 to 5 MHz.

4.1.2 The ultrasonic instrument shall provide linear presentation (within ±5%) for at least 75% of the screen height (sweep line to top of screen). Linearity shall be determined in accordance with Practice E 317 or equivalent electronic means.

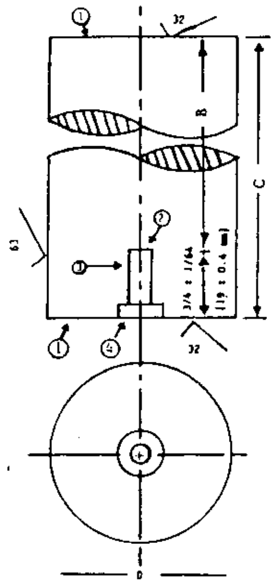
4.1.3 The electronic apparatus shall contain a signal attenuator or calibrated gain control that shall be accurate over its useful range to ±10% of the nominal attenuation or gain ratio to allow measurement of signals beyond the linear range of the instrument.

4.2 *Search Units:*

4.2.1 *Longitudinal Wave,* internally grounded, having a ½ to 1⅛ in. [13 to 28 mm] diameter or 1 in. [25 mm] square piezo-electric elements. Based on the signals-to-noise ratio of the response pattern of the casting, a frequency in the range from 1 to 5 MHz shall be used. The background noise shall not exceed 25% of the distance–amplitude correction curve (DAC). Transducers shall be utilized at their rated frequencies.

4.2.2 *Dual-Element,* 5 MHz, ½ by 1 in. [13 by 25 mm], 12° included angle search units are recommended for sections 1 in. [25 mm] and under.

4.2.3 Other frequencies and sizes of search units may be used for evaluating and pinpointing indications.



NOTE 1—Opposite ends of reference block shall be flat and parallel within 0.001 in. [0.025 mm].

NOTE 2—Bottom of flat-bottom hole shall be flat within 0.002-in. [0.051 mm] and the finished diameter shall be ¼ + 0.002 in. [6.4 + 0.050 mm].

NOTE 3—Hole shall be straight and perpendicular to entry surface within 0°, 30 min and located within $\frac{1}{32}$ in. [0.80 mm] of longitudinal axis.

NOTE 4—Counter bore shall be ½ in. [15.0 mm] diameter by ⅛ in. [5 mm] deep.

FIG. 1 ULTRASONIC STANDARD REFERENCE BLOCK

4.3 *Reference Blocks:*

4.3.1 Reference blocks containing flat-bottom holes shall be used to establish test sensitivity in accordance with 8.2.

4.3.2 Reference blocks shall be made from cast steels that give an acoustic response similar to the castings being examined.

4.3.3 The design of reference blocks shall be in accordance with Fig. 1, and the basic set shall consist of those blocks listed in Table 1. When section thicknesses over 15 in. [380 mm] are to be inspected, an additional block of the maximum test thickness shall be made to supplement the basic set.

4.3.4 Machined blocks with $\frac{3}{32}$-in. [2.4-mm] diameter flat-bottom holes at depths from the entry surface of ⅛ in. [3 mm], ½ in. [13 mm], or ½t and ¾ in. [19 mm], or ¾t (where t = thickness of the block) shall be used to establish the DAC for the dual-element search units (see Fig. 2).

TABLE 1
DIMENSIONS AND IDENTIFICATION OF REFERENCE BLOCKS IN THE BASIC SET (SEE FIG. 1)

Hole Diameter in $\frac{1}{64}$ths, in. [mm]	Metal Distance (B), in.[A] [mm]	Overall Length (C), in. [mm]	Width or Diameter (D), min, in. [mm]	Block Identification Number
16 [6.4]	1 [25]	$1\frac{3}{4}$ [45]	2 [50]	16-0100
16 [6.4]	2 [50]	$2\frac{3}{4}$ [70]	2 [50]	16-0200
16 [6.4]	3 [75]	$3\frac{3}{4}$ [95]	2 [50]	16-0300
16 [6.4]	6 [150]	$6\frac{3}{4}$ [170]	3 [75]	16-0600
16 [6.4]	10 [255]	$10\frac{3}{4}$ [275]	4 [100]	16-1000
16 [6.4]	B	B + $\frac{3}{4}$ [B + 20]	5 [125]	16-B00[B]

[A] Tolerance ± $\frac{1}{8}$ in. [3 mm].
[B] Additional supplemental blocks for testing thickness greater than 10 in. [250 mm], see 4.3.3.

4.3.5 Each reference block shall be permanently identified along the side of the block indicating the material and the block identification.

4.4 *Couplant* — A suitable couplant having good wetting characteristics shall be used between the search unit and examination surface. The same couplant shall be used for calibrations and examinations.

5. Personnel Requirements

5.1 The manufacturer shall be responsible for assigning qualified personnel to perform ultrasonic examination in conformance with the requirements of this practice.

5.2 Personnel performing ultrasonic examinations in accordance with this practice shall be familiar with the following:

5.2.1 Ultrasonic terminology,

5.2.2 Instrument calibration,

5.2.3 Effect of transducer material, size, frequency, and mode on test results,

5.2.4 Effect of material structure (grain size, cleanliness, etc.) on test results,

5.2.5 Effect of test distance on test results,

5.2.6 Effect of nonlinearity on test results,

5.2.7 Effect of thickness and orientation of discontinuities on test results, and

5.2.8 Effect of surface roughness on test results.

5.3 A qualification record (see Note 2) of personnel considered suitable by the manufacturer to perform examinations in accordance with this practice shall be available upon request.

NOTE 2 — SNT-TC-1A, Ultrasonic Testing Method, provides a recommended procedure for qualifying personnel. Other personnel qualification requirement documents may be used when agreed upon between the purchaser and the supplier.

6. Casting Conditions

6.1 Castings shall receive at least an austenitizing heat treatment before being ultrasonically examined.

6.2 Test surfaces of castings shall be free of material that will interfere with the ultrasonic examination. They may be as cast, blasted, ground, or machined.

6.3 The ultrasonic examination shall be conducted prior to machining that prevents an effective examination of the casting.

7. Test Conditions

7.1 To assure complete coverage of the specified casting section, each pass of the search unit shall overlap by at least 10% of the width of the transducer.

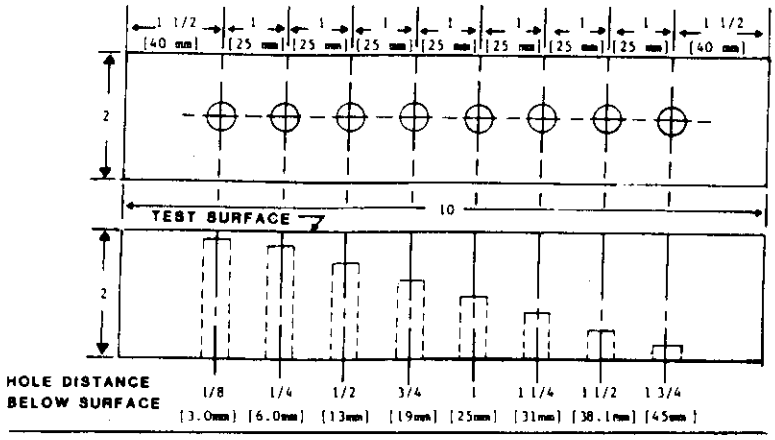
7.2 The rate of scanning shall not exceed 6 in./s (150 mm/s).

7.3 The ultrasonic beam shall be introduced perpendicular to the examination surface.

8. Procedure

8.1 Adjust the instrument controls to position the first back reflection for the thickness to be tested at least one half of the distance across the cathode ray tube.

8.2 Using the set of reference blocks spanning the thickness of the casting being inspected, mark the flat-bottom hole indication height for each of the applicable blocks on the cathode ray tube shield. Draw a curve through these marks on the screen or on suitable graph paper. The maximum signal amplitude for the test blocks used shall peak at approximately three-fourths of the screen height above the sweep by use of the attenuator. This curve shall be referred to as the 100% distance–amplitude correction (DAC) curve. If the attenuation of ultrasound in the casting thickness being examined is such that the system's dynamic range is exceeded, segmented DAC curves are permitted.



NOTE 1—Entrant surface shall be 250 μin. [6.3 μm] or finer.

NOTE 2—The 3/32-in. [2.4 mm] flat-bottom hole must be flat within 0.002 in. [0.05 mm]. Diameter must be within +0.005 in. [0.13 mm] of the required diameter. Hole axis must be perpendicular to the block and within an angle of 0°, 30 min.

NOTE 3—Hole shall be plugged following checking for ultrasonic response.

in.	[mm]	in.	[mm]
1/8	[3]	1 1/4	[32]
1/4	[6]	1 1/2	[38]
1/2	[13]	1 3/4	[44]
3/4	[19.0]	2	[50]
1	[25]	10	[254]

FIG. 2 ULTRASONIC STANDARD REFERENCE BLOCK FOR DUAL-SEARCH UNIT CALIBRATION

8.3 The casting examination surface will normally be rougher than that of the test blocks; consequently, employ a transfer mechanism to provide approximate compensation. In order to accomplish this, first select a region of the casting that has parallel walls and a surface condition representative of the rest of the casting as a transfer point. Next, select the test block whose overall length, *C* (Fig. 1), most closely matches the reflection amplitude through the block length. Place the search unit on the casting at the transfer point and adjust the instrument gain until the back reflection amplitude through the casting matches that through the test block. Using this transfer technique, the examination sensitivity in the casting may be expected to be within ±30% or less of that given by the test blocks.

8.4 Do not change those instrument controls and the test frequency set during calibration, except the attenuator, or calibrated gain control, during acceptance examination of a given thickness of the casting. Make a periodic calibration during the inspection by checking the amplitude of response from the 1/4-in. (6.4-mm) diameter flat-bottom hole in the test block utilized for the transfer.

NOTE 3 — The attenuator or calibrated gain control may be used to change the signal amplitude during examination to permit small amplitude signals to be more readily detected. Signal evaluation is made by returning the attenuator or calibrated gain control to its original setting.

8.5 During examination of areas of the casting having parallel walls, recheck areas showing 75% or greater loss of back reflection to determine whether loss of back reflection is due to poor contact, insufficient couplant, misoriented discontinuity, etc. If the reason for loss of back reflection is not evident, consider the area questionable and further investigate.

9. Report

9.1 The manufacturer's report of final ultrasonic examination shall contain the following data and shall be furnished to the purchaser:

9.1.1 The total number, location, amplitude, and area when possible to delineate boundaries by monitoring the movement of the center of the search unit of all indications equal to or greater than 100% of the DAC,

9.1.2 Questionable areas from 8.5 that, upon further investigation, are determined to be caused by discontinuities,

9.1.3 The examination frequency, type of instrument, types of search units employed, couplant, manufacturer's identifying numbers, purchaser's order number, and data and authorized signature, and

9.1.4 A sketch showing the physical outline of the casting, including dimensions of all areas not inspected due to geometric configuration, with the location and sizes of all indications in accordance with 9.1.1 and 9.1.2.

10. Acceptance Standards

10.1 This practice is intended for application to castings with a wide variety of sizes, shapes, compositions, melting processes, foundry practices, and applications. Therefore, it is impractical to specify an ultrasonic quality level that would be universally applicable to such a diversity of products. Ultrasonic acceptance or rejection criteria for individual castings should be based on a realistic appraisal of service requirements and the quality that can normally be obtained in production of the particular type of casting.

10.2 Acceptance quality levels shall be established between the purchaser and the manufacturer on the basis of one or more of the following criteria:

10.2.1 No indication equal to or greater than the DAC over an area specified for the applicable quality level of Table 2.

10.2.2 No reduction of back reflection of 75% or greater that has been determined to be caused by a discontinuity over an area specified for the applicable quality level of Table 2.

10.2.3 Indications producing a continuous response equal to or greater than the DAC with a dimension exceeding the maximum length shown for the applicable quality level shall be unacceptable.

10.2.4 Other criteria agreed upon between the purchaser and the manufacturer.

10.3 Other means may be used to establish the validity of a rejection based on ultrasonic inspection.

NOTE 4 — The areas for the ultrasonic quality levels in Table 2 of Practice A 609/A 609M refer to the surface area on the casting over which a continuous indication exceeding the DAC is maintained.

NOTE 5 — Areas are to be measured from dimensions of the movement of the search unit by outlining locations where the amplitude of the indication is 100% of the DAC or where the back reflection is reduced by 75%, using the center of the search unit as a reference point to establish the outline of the indication area.

NOTE 6 — In certain castings, because of very long metal path distances or curvature of the examination surfaces, the surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting; in such cases, other criteria that incorporate a consideration of beam angles or beam spread must be used for realistic evaluation of the discontinuity.

TABLE 2
REJECTION LEVEL

Ultrasonic Testing Quality Level	Area, in.^{2} [cm^2] (see 10.2.1 and 10.2.2)	Length, max, in. [mm]
1	0.8 [5]	1.5 [40]
2	1.5 [10]	2.2 [55]
3	3 [20]	3.0 [75]
4	5 [30]	3.9 [100]
5	8 [50]	4.8 [120]
6	12 [80]	6.0 [150]
7	16 [100]	6.9 [175]

Note 1—The areas in the table refer to the surface area on the casting over which a continuous indication exceeding the amplitude reference line or a continuous loss of back reflection of 75% or greater is maintained.
Note 2—Areas shall be measured from the center of the search unit.
Note 3—In certain castings, because of very long test distances or curvature of the test surface, the casting surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting; in such cases a graphic plot that incorporates a consideration of beam spread should be used for realistic evaluation of the discontinuity.

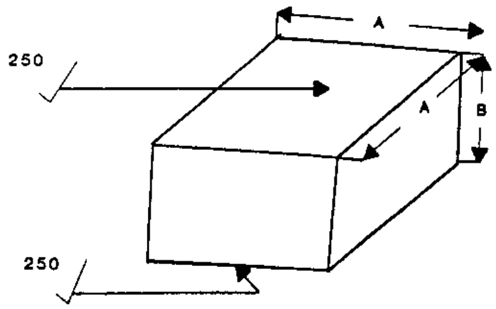
PROCEDURE B — BACK-WALL REFLECTION CALIBRATION PROCEDURE

11. Apparatus

11.1 Apparatus shall be kept on a regular six month maintenance cycle during which, as a minimum requirement, the vertical and horizontal linearities, sensitivity, and resolution shall be established in accordance with the requirements of Practice E 317.

11.2 *Search Units* — Ceramic element transducers not exceeding 1.25 in. [32 mm] diameter or 1 in.^{2} [645 mm^2] shall be used.

11.3 *Search Units Facing* — A soft urethane membrane or neoprene sheet, approximately 0.025 in. [0.64 mm] thick, may be used to improve coupling and minimize transducer wear caused by casting surface roughness.



Dimensions, in. [mm]		Material
2 [50]	½ [13]	Specification A 217/A 217M, Grade WC6 or acoustically similar within ±20 % or 2 dB.
2 [50]	2 [50]	
3 [75]	5 [125]	
6 [150]	10 [250]	

Tolerance

All sides to be flat within 0.0002 in. [0.01 mm] and parallel with 0.001 in. [0.03 mm].

FIG. 3 CALIBRATION BLOCKS

11.4 *Calibration/Testing* — The same system, including the urethane membrane, used for calibration shall be used to inspect the casting.

11.5 *Other Inspections* — Other frequencies and type search units may be used for obtaining additional information and pinpointing of individual indications.

11.6 *Couplant* — A suitable liquid couplant, such as clean SAE 30 motor oil or similar commercial ultrasonic couplant, shall be used to couple the search unit to the test surface. Other couplants may be used when agreed upon between the purchaser and supplier.

11.7 *Reference Standards* — Reference standards in accordance with Fig. 3 shall be used to calibrate the instrument for inspecting machined and cast surfaces. Reference standards shall be flaw free and machined within tolerances indicated.

12. Ultrasonic Instrument

12.1 *Type* — Pulsed ultrasonic reflection instrument capable of generating, receiving, and amplifying frequencies of 1 MHz to 5 MHz shall be used for testing.

12.2 *Voltage* — Line voltage shall be suitably regulated by constant voltage equipment and metal housing must be grounded to prevent electric shock.

12.3 *Linearity* — The instrument must provide a linear presentation (within ±5%) of at least 1.5 in. [40 mm] sweep to peak (S/P).

12.4 *Calibrated Gain Control of Attenuator* — The instrument shall contain a calibrated gain control or signal attenuator (accurate within ±10%) which will allow indications beyond the linear range of the instrument to be measured.

12.5 *Time-Corrected Gain* — The instrument shall be equipped to compensate for signal decay with distance. A method should be available to equalize signal response at different depths.

13. Qualification

13.1 The requirements for pre-production qualification are as follows:

13.1.1 *Personnel* — The personnel qualification requirements of SNT-TC-1A are applicable. Other personnel qualification requirement documents may be used when agreed upon between the purchaser and the supplier. Records of all personnel shall be available to customers upon request.

13.1.2 *Equipment* — The equipment shall be capable of meeting the requirements in Section 12.

14. Preparation

14.1 *Time of Inspection* — The final ultrasonic acceptance inspection shall be performed after at least an austenitizing heat treatment and preferably after machining. In order to avoid time loss in production, acceptance inspection of cast surfaces may be done prior to machining. Machined surfaces shall be acceptance inspected as soon as possible after machining. Repair welds may be inspected before the postweld heat treatment.

14.2 *Surface Finish:*

14.2.1 *Machined Surfaces* — Machined surfaces subject to ultrasonic inspection shall have a finish that will produce an ultrasonic response equivalent to that obtained from a 250 μin. (6.3 μm) surface. The surface finish shall also permit adequate movement of search units along the surface.

14.2.2 *Casting Surfaces* — Casting surfaces to be ultrasonically inspected shall be suitable for the

TABLE 3
ACCEPTANCE CRITERIA FOR SINGLE ISOLATED INDICATIONS

Quality Level	Maximum Nonlinear Indication, Area, in.^{2} [cm^2]	Position of Indication
1	0	E
2	1 [6]	E
3	1 [6]	O
	2 [13]	C
4	3 [19]	E
5	3 [19]	O
	5 [32]	C
6	5 [32]	E
7	5 [32]	O
	7 [45]	C
8	7 [45]	E
9	7 [45]	O
	9 [58]	C
10	9 [58]	E
11	9 [58]	O
	11 [71]	C

Note 1 — The area measured by movement of the center of the transducer over the casting surface.
Note 2 — O = outer wall 1/3, or inner wall 1/3.
C = midwall 1/3.
E = entire wall.

TABLE 4
ACCEPTANCE CRITERIA FOR CLUSTERED INDICATIONS

Quality Level	Cumulative Area of Indications, in.^{2} [cm^2]$^{A, B}$	Minimum Area in Which Indications Must Be Dispersed, in.^{2} [cm^2]^{C}
1	0	0
2–3	2 [13]	36 [232]
4–5	4 [26]	36 [232]
6–7	6 [39]	36 [232]
8–9	8 [52]	36 [232]
10–11	10 [64]	36 [232]

[A] Regardless of wall location, that is midwall 1/3, innermost 1/3, or outermost 1/3.
[B] Each indication that equals or exceeds the 0.5-in. [18 mm] reference line shall be traced to the position where the indication is equal to 0.25 in. [6 mm]. The area of the location, for the purpose of this evaluation, shall be considered the area that is confined within the outline established by the center of the transducer during tracing of the flaw as required. Whenever no discernible surface tracing is possible, each indication which equals or exceeds the 0.5 in. reference amplitude shall be considered 0.15 in.^{2} [1 cm^2] (three times the area of the 1/4 diameter [6 mm] flat-bottomed hole to compensate for reflectivity degradation of natural flaw) for the cumulative area estimates.
[C] The indications within a cluster with the cumulative areas traced shall be dispersed in a minimum surface area of the casting equal to 36 in.^{2} [230 cm^2]. If the cumulative areas traced are confined with a smaller area of distribution, the area shall be repair welded to the extent necessary to meet the applicable quality level.

intended type and quality level (Tables 3 and 4) of inspection as judged acceptable by a qualified individual as specified in 13.1.1.

14.2.3 *Surface Condition* — All surfaces to be inspected shall be free of scale, machining or grinding particles, excessive paint thickness, dirt, or other foreign matter that may interfere with the inspection.

14.3 *Position of Casting* — The casting shall be positioned such that the inspector has free access to the back wall for the purpose of verifying change in contour.

15. Calibration

15.1 *Calibration Blocks* — Determine the thickness of the material to be ultrasonically inspected. For material thickness of 3 in. [75 mm] or less, use the series of 3 blocks, 1/2, 2, 5 in. [13, 50, 125 mm] (Fig. 3, B dimension) for calibration. For a material thickness greater than 3 in., use the series of 3 blocks, 2, 5, 10 in. [50, 125, 250 mm] (Fig. 3, B dimension) for calibration.

15.2 *Calibration of Search Units* — For the thickness of material to be inspected, as determined in 15.1, use the following search units:

15.2.1 For materials 3 in. [75 mm] or less in thickness, use a 2 1/4 MHz, 1/2 in. [13 mm] diameter search unit.

15.2.2 For material greater than 3 in. [75 mm] in thickness, use a 2 1/4 MHz, 1 in. [25 mm] diameter search unit.

15.3 *Calibration Procedure:*

15.3.1 Set the frequency selector as required. Set the reject control in the "OFF" position.

15.3.2 Position the search unit on the entrant surface of the block that completely encompasses the metal thickness to be inspected (Fig. 3) and adjust the sweep control such that the back reflection signal appears approximately, but not more than three-quarters along the sweep line from the initial pulse signal.

15.3.3 Position the search unit on the entrant surface of the smallest block of the series of 3 blocks selected for calibration and adjust the gain until the back reflection signal height (amplitude) is 1.5 in. [40 mm] sweep to peak (S/P). Draw a line on the cathode-

ray screen (CRT), parallel to the sweep line, through the peak of the 1.5 in. (S/P) amplitude.

15.3.4 Position the search unit on the entrant surface of the largest block of the series of 3 blocks selected for calibration, and adjust the distance–amplitude control to provide a back reflection signal height of 1.5 in. [40 mm] (S/P).

15.3.5 Position the search unit on the entrant surface of the intermediate calibration block of the series of 3 blocks being used for calibration and confirm that the back reflection signal height is approximately 1.5 in. [40 mm] (S/P). If it is not, obtain the best compromise between this block and the largest block of the series of 3 blocks being used for calibration.

15.3.6 Draw a line on the cathode ray tube screen parallel to the sweep line at 0.5 in. [13 mm] (S/P) amplitude. This will be the reference line for reporting discontinuity amplitudes.

15.3.7 For tests on *machined surfaces*, position the search unit on a machined surface of casting where the walls are reasonably parallel and adjust the gain of the instrument until the back reflection signal height is 1.5 in. [40 mm] (S/P). Increase the inspection sensitivity by a factor of three times (10 dB gain) with the calibrated attenuator. Surfaces that do not meet the requirements of 14.2.1 shall be inspected as specified in 15.3.8.

15.3.8 For inspections on *cast surfaces*, position the search unit on the casting to be inspected at a location where the walls are reasonably parallel and smooth (inside and outside diameter) and the surface condition is representative of the surface being inspected. Adjust the gain of the instrument until the back reflection signal height is 1.5 in. [40 mm] (S/P). Increase the inspection sensitivity by a factor of six times (16 dB) by use of the calibrated control or attenuator. A significant change in surface finish requires a compensating adjustment to the gain.

15.3.8.1 Rejectable indications on as-cast surfaces may be reevaluated by surface preparation to 250 μin. [6.3 μm] finish or better, and reinspected in accordance with 15.3.7 of this practice.

15.3.8.2 It should be noted that some instruments are equipped with decibel calibrated gain controls, in which case the decibel required to increase the sensitivity must be added. Other instruments have decibel calibrated attenuators, in which case the required decibel must be removed. Still other instruments do not have calibrated gains or attenuators. They require external attenuators.

16. Scanning

16.1 *Grid Pattern* — The surface of the casting shall be laid out in a 12 by 12 in. [300 by 300 mm] or any similar grid pattern for guidance in scanning. Grid numbers shall be stenciled on the casting for record purposes and for grid area identity. The stenciled grid number shall appear in the upper right hand corner of the grid. When grids are laid out on the casting surface and they encompass different quality levels, each specific area shall be evaluated in accordance with the requirements of the specific quality level designated for that area.

16.2 *Overlap* — Scan over the surface allowing 10% minimum overlap of the working diameters of the search unit.

16.3 *Inspection Requirements* — All surfaces specified for ultrasonic (UT) shall be completely inspected from both sides, whenever both sides are accessible. The same search unit used for calibration shall be used to inspect the casting.

17. Additional Transducer Evaluation

17.1 Additional information regarding any ultrasonic indication may be obtained through the use of other frequency, type, and size search unit.

18. Acceptance Criteria

18.1 *Rejectable Conditions* — The locations of all indications having amplitudes greater than the 0.5 in. [13 mm] line given in 15.3.6, when amplitude three times (machined surfaces) or six times (cast surfaces) shall be marked on the casting surface. The boundary limits of the indication shall be determined by marking a sufficient number of marks on the casting surfaces where the ultrasonic signal equals one half the reference amplitude, 0.25 in. [6 mm]. To completely delineate the indication, draw a line around the outer boundary of the center of the number of marks to form the indication area. Draw a rectangle or other regular shape through the indication in order to form a polygon from which the area may be easily computed. It is not necessary that the ultrasonic signal exceed the amplitude reference line over the entire area. At some locations within the limits of the indication, the signal may be

less than the reference line, but nevertheless still present such that it may be judged as a continuous, signal indication. Rejectable conditions are as follows and when any of the conditions listed below are found, the indications shall be removed and repair welded to the applicable process specification.

18.2 *Linear Indications* — A linear indication is defined as one having a length equal to or greater than three times its width. An amplitude of $\frac{1}{2}$ in. [13 mm], such as would result from tears or stringer type slag inclusion, shall be removed.

18.3 *Non-Linear Indications:*

18.3.1 *Isolated Indications* — Isolated indications shall not exceed the limits of the quality level designated by the customer's purchase order listed in Table 3. An isolated indication may be defined as one for which the distance between it and an adjacent indication is greater than the longest dimension of the larger of the adjacent indications.

18.3.2 *Clustered Indications* — Clustered indications shall be defined as two or more indications that are confined in a 1 in. [25 mm] cube. Clustered indications shall not exceed the limits of the quality level designated by the customer purchase order in Table 4. Where the distance between indications is less than the lowest dimension of the largest indication in the group, the cluster shall be repair welded.

18.3.3 The distance between two clusters must be greater than the lowest dimension of the largest indication in either cluster. If they are not, the cluster having the largest single indication shall be removed.

18.3.4 All indications, regardless of their surface areas as indicated by transducer movement on the casting surface and regardless of the quality level required, shall not have a through wall distance greater than $\frac{1}{3}T$, where T is the wall thickness in the area containing the indication.

18.3.5 Repair welding of cluster-type indications need only be the extent necessary to meet the applicable quality level for that particular area. All other types of rejectable indications shall be completely removed.

18.3.6 Repair welds of castings shall meet the quality level designated for that particular area of the casting.

18.3.7 Any location that has a 75% or greater loss in back reflection and exceeds the area of the applicable quality level, and whose indication amplitudes may or may not exceed the 0.5 in. [13 mm] rejection line, shall be rejected unless the reason for the loss in back reflection can be resolved as not being caused by an indication. If gain is added and back echo is achieved without indication percent amplitude exceeding the 0.5 in. [13 mm] rejection line, the area should be accepted.

19. Records

19.1 *Stenciling* — Each casting shall be permanently stenciled to locate inspection zones or grid pattern for ease in locating areas where rejectable indications were observed.

19.2 *Sketch* — A report showing the exact depth and surface location in relation to the stencil numbers shall be made for each rejectable indicator found during each inspection.

19.2.1 The sketch shall also include, but not be limited to, the following:

19.2.1.1 Part identification numbers,

19.2.1.2 Purchase order numbers,

19.2.1.3 Type and size of supplemental transducers used,

19.2.1.4 Name of inspector, and

19.2.1.5 Date of inspection.

20. Product Marking

20.1 Any rejectable areas (those indications exceeding the limits of Section 19) shall be marked on the casting as the inspection progresses. The point of marking shall be the center of the search unit.

21. Keywords

21.1 carbon and low-alloy steel; castings; martensitic stainless steel; ultrasonic

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall be applied only when agreed upon between the purchaser and the supplier to achieve an effective examination of a critical casting area that cannot be effectively examined using a longitudinal beam as a result of casting design or possible discontinuity orientation.

S1. Angle Beam Examination of Steel Castings

S1.1 *Equipment:*

S1.1.1 *Examination Instrument* — Examination shall be conducted with an ultrasonic, pulsed-reflection type of system generating frequencies of at least 0.4 to 5 MHz. Properties of the electronic apparatus shall be the same as those specified in 4.1.

S1.1.2 *Search Units* — Angle-beam search units shall produce an angle beam in steel in the range from 30 to 75° inclusive, measured to the perpendicular of the entry surface of the casting being examined. It is preferred that search units shall have frequency of 0.4 to 5 MHz.

S1.1.3 *Calibration Blocks* — A set of blocks, as shown in Fig. S1.1, with as cast surface equivalent to SCRATA Comparator A3 and of a thickness comparable to the sections being examined with side-drilled holes at $\frac{1}{4}t$, $\frac{1}{2}t$, and $\frac{3}{4}t$ (where t = thickness of the block) shall be used to establish an amplitude reference line (ARL).

S1.2 *Calibration of Equipment:*

S1.2.1 Construct the distance–amplitude correction curve by utilizing the responses from the side-drilled holes in the basic calibration block for angle beam examination as shown in Fig. S1.1 and Table S1.1.

S1.2.1.1 Resolve and mark the amplitudes of the $\frac{1}{4}t$ and $\frac{1}{2}t$ side-drilled holes from the same surface. The side-drilled hole used for the $\frac{1}{4}t$ amplitude may be used to establish the $\frac{3}{4}t$ amplitude from the opposite surface or a separate hole may be used.

S1.2.1.2 Connect the $\frac{1}{4}t$, $\frac{1}{2}t$, and $\frac{3}{4}t$ amplitudes to establish the applicable DAC.

S1.2.2 The basic calibration blocks shall be made of material that is acoustically similar to the casting being examined.

S1.2.3 Do not use basic calibration blocks with as cast surface equivalent to SCRATA Comparator A3 to examine castings with surface rougher than SCRATA Comparator A3. Use a machined calibration block for machined surfaces.

S1.2.4 The search unit and all instrument control settings remain unchanged except the attenuator or calibrated gain control.

S1.2.4.1 The attenuator or calibrated gain control may be used to change the signal amplitude during examination to permit small amplitude signals to be more readily detected. Signal evaluation is made by returning the attenuator or calibrated gain control to its original setting.

S1.3 *Data Reporting* — The supplier's report of final ultrasonic examination shall contain the following data:

S1.3.1 The total number, location, amplitude, and area of all indications equal to or greater than 100% of the distance–amplitude curve.

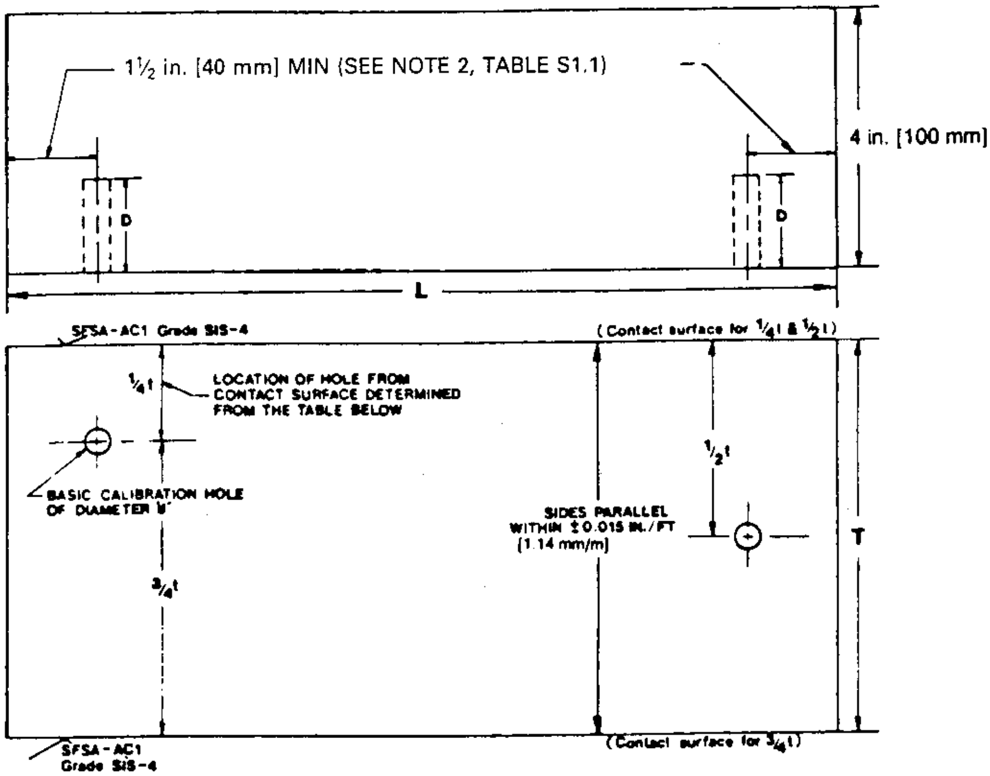
S1.3.2 The examination frequency, type of instrument, type and size of search units employed, couplant, transfer method, examination operator, supplier's identifying numbers, purchase order number, date, and authorized signature.

S1.3.3 A sketch showing the physical outline of the casting, including dimensions of all areas not examined due to geometric configuration, with the location of all indications in accordance with S1.3.1.

S1.4 *Acceptance Standards* — Acceptance quality levels shall be established between the purchaser and the manufacturer on the basis of one or more of the following criteria:

S1.4.1 No indication equal to or greater than the DAC over an area specified for the applicable quality level of Table 2.

S1.4.2 Other criteria agreed upon between the purchaser and the manufacturer.



L = length of block determined by the angle of search unit and the vee-path used,
T = thickness of basic calibration block (see Table S1.1),
D = depth of side-drilled hole (see Table S1.1),
d = diameter of side-drilled hole (see Table S1.1),
t = nominal production material thickness.

FIG. S1.1 BASIC CALIBRATION BLOCK FOR ANGLE-BEAM EXAMINATION

TABLE S1.1
DIMENSIONS OF CALIBRATION BLOCKS FOR ANGLE-BEAM EXAMINATION

Nominal Production Material Thickness (t), in. [mm]	Basic Calibration Block Thickness (T), in. [mm]	Hole Diameter (d), in. 1.002 [mm ± 0.05]	Minimum Depth (D), in. [mm]
Up to 1 [25] incl.	1 [25] or t	$^3/_{32}$ [2.4]	$1\frac{1}{2}$ [40]
Over 1 to 2 [25–50]	2 [50] or t	$^1/_8$ [3.2]	$1\frac{1}{2}$ [40]
Over 2 to 4 [50–100]	4 [100] or t	$^3/_{16}$ [4.8]	$1\frac{1}{2}$ [40]
Over 4 to 6 [100–150]	6 [150] or t	$^1/_4$ [6.3]	$1\frac{1}{2}$ [40]
Over 6 to 8 [150–200]	8 [200] or t	$^5/_{16}$ [7.9]	$1\frac{1}{2}$ [40]
Over 8 to 10 [200–250]	10 [250] or t	$^3/_8$ [9.5]	$1\frac{1}{2}$ [40]
Over 10 [250]	t	See Note 1	$1\frac{1}{2}$ [40]

Note 1 — For each increase in thickness of 2 in. [50 mm], or a fraction thereof, the hole diameter shall increase $^1/_{16}$ in. [1.6 mm].
Note 2 — For block sizes over 3 in. [75 mm] in thickness, T, the distance from the hole to the end of the block shall be $\frac{1}{2}T$, min, to prevent coincident reflections from the hole and the corner. Block fabricated with a 2-in. [50-mm] minimum dimension need not be modified if the corner and hole indications can be easily resolved.

STANDARD PRACTICE FOR ULTRASONIC EXAMINATION OF AUSTENITIC STEEL FORGINGS

SA-745/SA-745M

(Identical with ASTM Specification A 745/A 745M-94)

1. Scope

1.1 This practice covers the standards and procedures for the contact, pulse-echo ultrasonic examination of austenitic steel forgings by the straight or angle beam techniques, or both.

1.2 This practice shall be used whenever the inquiry, proposal, contract, order, or specification states that austenitic steel forgings are to be subject to ultrasonic examination in accordance with Practice A 745/A 745M. Ultrasonic examination of nonmagnetic retaining ring forgings should be made to Practice A 531, not to this practice.

1.3 The values stated in either inch-pound or SI units are to be regarded as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the practice.

1.4 This practice and the applicable material specifications are expressed in both inch-pound units and SI units. However, unless the order specifies the applicable "M" specification designation (SI units), the material shall be furnished to inch-pound units.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 531/A 531M Practice for Ultrasonic Inspection of Turbine-Generator Steel Retaining Rings

E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems Without the Use of Electronic Measurement Instruments

E 428 Practice for Fabrication and Control of Steel Reference Blocks Used in Ultrasonic Inspection

2.2 *American Society for Nondestructive Testing Document:*

SNT-TC-1A Recommended Practice for Nondestructive Personnel Qualification and Certification

3. Ordering Information

3.1 When this practice is to be applied to an inquiry or purchase order, the purchaser shall furnish the following information:

3.1.1 Quality level of examination (see Section 12).

3.1.2 Additional requirements to this practice.

3.1.3 Applicability of supplementary requirements (see Supplementary Requirements section).

3.2 When specified, the manufacturer shall submit an examination procedure for purchaser approval that shall include, but not be limited to, a sketch of the configuration as presented for ultrasonic examination showing the surfaces to be scanned, scanning directions, notch locations and sizes (if applicable), extent of coverage (if applicable), and an instruction listing calibration and inspection details and stage of manufacture.

4. Apparatus

4.1 An electronic, pulsed, reflection type of instrument shall be used for this examination. The system shall have a minimum capability for operating at frequencies from 0.5 to 5.0 MHz. Either video or r-f presentation is acceptable.

4.2 The ultrasonic instrument shall provide linear presentation (within ±5% of the signal height) for at least 75% of the screen height (sweep line to top of screen). This 5% linearity is descriptive of the screen presentation of amplitude. Instrument linearity shall be verified in accordance with the intent of Practice E 317.

4.3 Instruments with incremental gain control (accurate over its useful range to ±10% of the nominal attenuation ratio) shall be used when possible to allow measurement of signals beyond the linear display range of the instrument.

4.4 *Search Units:*

4.4.1 Search units having transducers of either quartz or other piezoelectric materials may be employed.

4.4.2 The maximum nominal active area of $1\frac{1}{2}$ in.^{2} [970 mm^2] with $\frac{1}{2}$ in. [13 mm] minimum to $1\frac{1}{8}$ in. [30 mm] maximum dimensions or $\frac{3}{4}$-in. [20-mm] diameter minimum dimension shall be used for straight-beam scanning.

4.4.3 Angle-beam scanning transducers shall have a nominal active area of $\frac{1}{2}$ to 1 in.^{2} [325 to 650 mm^2]. The search unit used for angle-beam examination shall produce a beam angle of 30° to 70° in the material.

4.4.4 Other search units, including frequencies other than those listed in Section 8, may be used for evaluating and pinpointing indications of discontinuities.

4.5 *Couplant* — A suitable couplant having good wetting characteristics shall be used between the transducer and the examination surface. The same couplant shall be used for calibration and examination.

4.6 *Reference Blocks:*

4.6.1 All ultrasonic standard reference blocks shall be in accordance with the general guidelines of Practice E 428. However, absolute conformance to Practice E 428 is not mandatory due to the nature of the material covered by this practice.

4.6.2 The reference block grain size, as measured by the relative acoustic penetrability of the reference blocks, should be reasonably similar to the forging under examination. However, it must be recognized that large austenitic forgings vary considerably in acoustic penetrability throughout their volume due to variations in grain size and structure. Reference blocks should be chosen that reasonably approximate the average penetrability of the forging under examination. Supplementary blocks of coarser or finer grain may be used for evaluation of indications as covered in Section 11.

4.6.3 As an alternative method, where practicable, the appropriate size of reference hole (or holes) or notches may be placed in representative areas of the forging for calibration and examination purposes when removed by subsequent machining. When holes or notches are not removed by subsequent machining, the purchaser must approve the location of holes or notches.

5. Personnel Requirements

5.1 Personnel performing the ultrasonic examinations to this practice shall be qualified and certified in accordance with a written procedure conforming to Recommended Practice No. SNT-TC-1A or another national standard that is acceptable to both the purchaser and the supplier.

6. Forging Conditions

6.1 Forgings shall be ultrasonically examined after heat treating.

6.2 The surfaces of the forging to be examined shall be free of extraneous material such as loose scale, paint, dirt, etc.

6.3 The surface roughness of scanning surfaces shall not exceed 250 μin. [6 μm] unless otherwise stated in the order or contract.

6.4 The forgings shall be machined to a simple configuration, that is, rectangular or parallel or concentric surfaces where complete volumetric coverage can be obtained.

6.5 In certain cases, such as with contour forged parts, it may be impractical to assure 100% volumetric coverage. Such forgings shall be examined to the maximum extent possible. A procedure indicating the extent of examination coverage shall be submitted for the purchaser's approval (see 3.2).

7. Procedure

7.1 Perform the ultrasonic examination after heat treatment when the forging is machined to the ultrasonic

configuration but prior to drilling holes, cutting keyways, tapers, grooves, or machining sections to final contour.

7.2 To ensure complete coverage of the forging volume when scanning, index the search unit with at least 15% overlap with each pass.

7.3 The scanning rate shall not exceed 6 in. [150 mm]/s.

7.4 Scan all regions of the forging in at least two perpendicular directions to the maximum extent possible.

7.5 Scan disk and disk-type forgings using a straight beam from at least one flat face and radially from the circumference when practicable. For the purposes of this practice, a disk is a cylindrical shape where the diameter dimension exceeds the height dimension. Disk-type forgings made as upset-forged "pancakes" shall be classified as disks for inspection purposes although at the time of inspection, the part may have a center hole, counterturned steps, or other detail configuration.

7.6 Scan cylindrical sections, ring and hollow forgings from the entire external surface (sides or circumference), using the straight-beam technique, and scan the forging in the axial direction to the extent possible. When the length divided by the diameter ratio (slenderness ratio) exceeds 6 to 1 (or axial length exceeds 24 in. [600 mm]), scan axially from both end surfaces to the extent possible. If axial penetration is not possible due to attenuation, angle-beam examination directed axially may be substituted in place of axial straight beam. Examine ring and hollow forgings having an outside-diameter to inside-diameter ratio of less than 2 to 1 and a wall thickness less than 8 in. [200 mm] by angle-beam techniques from the outside diameter or inside diameter, or both, using full node or half-node technique (see 10.1.2 and 10.1.3) as necessary to achieve either 100% volumetric coverage or the extent of coverage defined by an approved procedure (see 3.2).

8. Examination Frequency

8.1 Perform all ultrasonic examination at the highest frequency practicable (as specified in 8.1.1, 8.1.2, or 8.1.3) that will adequately penetrate the forging thickness and resolve the applicable reference standard. Include in the ultrasonic examination report the examination frequency used. Determine the test frequency at the time of actual examination by the following guidelines:

8.1.1 The nominal test frequency shall be 2.25 MHz. Use of this frequency will generally be restricted due to attenuation.

8.1.2 One megahertz is acceptable and will be the frequency generally applicable.

8.1.3 When necessary, due to attenuation, 0.5 MHz examination frequency may be used. The purchaser may request notification before this lower frequency is employed.

8.1.4 In the event that adequate penetration of certain regions is not possible even at 0.5 MHz, alternative nondestructive examination methods (such as radiography) may be employed to ensure the soundness of the forging by agreement between the purchaser and the manufacturer.

9. Straight-Beam Examination

9.1 *Method of Calibration:*

9.1.1 Perform calibration for straight-beam examination on the flat-bottom hole size determined by the applicable quality level (see Section 12).

9.1.2 Determine the calibration method by the test metal distance involved.

9.1.2.1 Thicknesses up to 6 in. [150 mm] may be examined using either the single-block or the distance-amplitude curve calibration method.

(*a*) *Single-Block Method* — Establish the test sensitivity on the reference standard representing the forging thickness. Drill flat-bottom holes normal to the examining surface, to midsection in material up to 1.5 in. [40 mm] in thickness and at least 0.75 in. [20 mm] in depth but no deeper than midsection in thicknesses from 1.5 to 6 in. [40 to 150 mm]. Make evaluations of indications at the estimated discontinuity depth at which they are observed using supplementary reference standards, if necessary.

(*b*) *Distance–Amplitude Curve Correction Method* — Establish the test sensitivity on the reference standard whose metal travel distance represents the greater metal travel distance of the part under examination, within ±1 in. [25 mm].

9.1.2.2 Examine thicknesses from 6 to 24 in. [150 to 600 mm] using the distance–amplitude calibration method. Calibration to ½ thickness test metal distance may be used provided examinations from two opposing surfaces are made.

9.1.2.3 For metal travel distances over 24 in. [600 mm], perform one of the following examinations:

(*a*) Perform a back-reflection examination from at least one surface to QL-5 (see 12.1.1) or to a purchaser-approved procedure (see 3.2).

(*b*) On hollow-round forgings with wall thicknesses less than 8 in. [200 mm], perform an axial angle-beam scan in place of the straight-beam scan from the end surfaces. Calibration for this scan may be established on the existing axial notches required for the circumferential scan or on transverse oriented notches installed specifically for axial angle beam.

9.2 *Calibration Procedure* — Over an indication-free area of the forging and with the proper test frequency, adjust the amplitude of the back reflection to the maximum limit of vertical linearity of the instrument. The adjusted instrument sensitivity display shall be the primary calibration reference for both the single-block and multiple-block calibration methods. If, at this gain setting, the amplitude response from the flat-bottom hole in the longest calibration block is not equal to or greater than 0.5 in. [13 mm] sweep-to-peak, adjust the instrument gain further to obtain a 0.5 in. [13 mm] sweep-to-peak minimum response. To complete the distance–amplitude correction curve, determine the remaining points defining the shape of the curve at this adjusted gain setting and mark the curve on the shield of the cathode ray tube or plot on a graph. At least three blocks shall be used with test metal distances of 3 in. [75 mm] $\frac{1}{2}$ *T*, and *T*. However, the distance between any of the test blocks shall be $1\frac{1}{2}$ in. [40 mm] minimum. If indications closer than 3 in. [75 mm] from the initial pulse must be evaluated, an additional block with $1\frac{1}{2}$ in. [40 mm] test metal distance shall be used. This is the fixed reference against which all indications shall be evaluated at the maximum obtainable response at whatever depth the indications are observed. This will constitute an acceptable examination if there are no indications exceeding the acceptance limits. In large forgings, it is expected that a portion of the distance–amplitude curve will be above the vertical linearity limits of the instrument. If an indication appears in this area, readjust the instrument through the use of a calibrated gain control or through recalibration to the initial calibration level to bring the appropriate portion of the presentation on screen for evaluation of that specific area.

NOTE 1 — When flat surfaced reference block calibration is used for examination of forgings with surface curvature, compensation for curvature shall be made and the method for curvature correction shall be a matter of agreement between the producer and the purchaser. For diameters 80 in. [2000 mm] and over, no correction factor is required.

10. Angle-Beam Examination

10.1 Ring and hollow round forgings, as defined in 7.6, shall be angle-beam examined from their outer periphery in both circumferential directions employing the following method of calibration:

10.1.1 Notches of 1.25 in. [30 mm] maximum surface length, with the length perpendicular to sound propagation; depth based on quality level (Section 12), either rectangular with a width not greater than twice its depth or 60° minimum to 75° maximum included angle, located in the forging so as to produce no interference with each other, shall be used as calibration standards.

10.1.2 Determine the response from the inside and outside diameter calibration notches with the search unit positioned to produce the maximum response from each notch. Adjust the sensitivity of the ultrasonic equipment so that the indication from the notch at the greatest test metal distance is at least 0.5 in. [13 mm] sweep-to-peak. Draw a straight line connecting the peaks of the responses obtained from the inside and outside diameter notches. This shall be the primary reference line. This procedure is considered full node calibration.

10.1.3 In the event that a response of at least 0.5 in. [13 mm] sweep-to-peak cannot be obtained from both the inside and outside diameter notches, calibrate from both the outer periphery (the outside diameter surface) and the inside diameter surface. Adjust the sensitivity of the ultrasonic equipment so that the indication from the notch in the opposite surface is at least 0.5 in. [13 mm] sweep-to-peak in magnitude. This procedure is considered half-node calibration. Axial angle beam may be substituted for straight beam from the end surfaces, when specified.

NOTE 2 — Long cylinders or cylinders with small inside diameters are difficult to examine from the inside diameter surface. Normally, neither inside diameters smaller than 18 in. [450 mm] nor long cylinders exceeding 36 in. [900 mm] in length are scanned from the inside diameter surface.

11. Evaluation of Material

11.1 Coarse-grained austenitic materials frequently display sweep noise, particularly when an examination is performed at high sensitivities. For this reason, it is important to critically scrutinize reportable and rejectable indications to determine whether they result from defects or grain structure. It is desirable to have

several sets of calibration blocks with varying degrees of grain coarseness so that the attenuation of the defective area can be reasonably matched with a test block for a more accurate minimum defect size estimation. Due to the normal wide variation in attenuation throughout a given large austenitic forging, it is permissible to evaluate rejectable indications on the basis of alternative calibration blocks that compare more reasonably in attenuation to the defect area. It is also permissible to insert reference holes into representative areas of the forging itself, with the approval of the purchaser, to be used for calibration and evaluation of indications. Loss of back reflection results not only from internal discontinuities but also from coarse or nonuniform grain structures, variations in coupling, nonparallel reflecting surfaces, and other factors that must be considered before concluding that loss of back reflection resulted from discontinuities.

12. Quality Levels for Acceptance

12.1 One of the following quality levels may be specified by the purchaser:

12.1.1 *Straight Beam:*

12.1.1.1 Material producing an indication response whose maximized amplitude equals or exceeds 100% of the primary reference or distance–amplitude correction curve at the estimated discontinuity depth shall be considered unacceptable.

(*a*) *QL-1* — A distance–amplitude curve shall be based upon the amplitude response from No. 8 flat-bottom hole ($^8/_{64}$ in. [3 mm]).

(*b*) *QL-2* — A distance–amplitude curve shall be based upon the amplitude response from No. 16 flat-bottom hole ($^{16}/_{64}$ in. [6 mm]).

(*c*) *QL-3* — A distance–amplitude curve shall be based upon the amplitude response from No. 24 flat-bottom hole ($^{24}/_{64}$ in. [10 mm]).

(*d*) *QL-4* — A distance–amplitude curve shall be based upon the amplitude response from No. 32 flat-bottom hole ($^{32}/_{64}$ in. [13 mm]).

(*e*) *QL-5* — A back reflection examination shall be performed guaranteeing freedom from complete loss of back reflection accompanied by an indication of a discontinuity. For this purpose, a back reflection of less than 5% of full screen height shall be considered complete loss of back reflection.

12.1.1.2 The applicable quality level will necessarily vary with test metal distance, purchasers' requirements, and the type and size of forging involved. Large disks, rings, or solid forgings and complex forgings present extraordinary problems and quality level application shall be a matter of agreement between the manufacturer and the purchaser. For general guidance purposes, the following list of test metal distances versus quality level attainable is provided for general information.

(*a*) *QL-1* — Generally practical for thicknesses up to 3 in. [75 mm].

(*b*) *QL-2* — Generally practical for thicknesses up to 8 in. [200 mm].

(*c*) *QL-3* — Generally practical for thicknesses up to 12 in. [300 mm].

(*d*) *QL-4* — Generally practical for thicknesses up to 24 in. [600 mm].

(*e*) *QL-5* — Frequently practical for thicknesses over 24 in. [600 mm].

12.1.2 *Angle Beam* — Material producing indications with amplitudes equal to or exceeding the primary reference-acceptance line (full node calibration: see 10.1.2) at the estimated discontinuity depth observed shall be considered unacceptable. When examining with only one calibration notch (half node calibration: see 10.1.3), material containing indications of discontinuities equal to or exceeding the notch indication amplitude shall be considered unacceptable.

12.1.2.1 *QA-1* Angle beam reference acceptance shall be based on a notch depth of 3% of the thickness of the forging at the time of examination.

12.1.2.2 *QA-2* Angle beam reference acceptance line shall be based on a notch depth of the lesser of 5% of the thickness of the forging at the time of inspection, or $^3/_4$ in. [19.05 mm].

13. Reportable Indications

13.1 A record that shows the location and orientation of all indications or groups of indications with amplitudes as defined below shall be submitted to the purchaser for information.

13.1.1 Indications accompanied by a loss of back reflection of 75% of screen height. Similar loss in back reflection without indications shall be scanned at lower frequencies; if unsuccessful, the area shall be reported as "not inspected."

13.1.2 Indications distinct from the normal noise level and traveling to the left or right on the cathode

ray tube with movement of the transducer 1.0 in. [25 mm] or more over the surface of the forging.

13.1.3 Indications equal to or exceeding 50% of the applicable reference acceptance curve (both straight and angle beam).

14. Keywords

14.1 acceptance criteria; austenitic forgings; contact method; ultrasonic examination

SUPPLEMENTARY REQUIREMENTS

Supplementary requirements shall apply only when specified by the purchaser in the inquiry or order. Details of these supplementary requirements shall be agreed upon between the manufacturer and the purchaser.

S1. Angle Beam Calibration Based on Final Thickness

S1.1 The depth of the calibration notch (see 12.1.2) shall be based upon the final ordered thickness of the forging rather than the thickness at the time of inspection.

STANDARD METHOD FOR ULTRASONIC INSPECTION OF ALUMINUM-ALLOY PLATE FOR PRESSURE VESSELS

SB-548

(Identical with ASTM Specification B 548-90)

1. Scope

1.1 This method covers pulse-echo ultrasonic inspection of aluminum-alloy plate of thickness equal to or greater than 0.500 in. (12.7 mm) for use in the fabrication of pressure vessels. The ultrasonic test is employed to detect gross internal discontinuities oriented in a direction parallel to the rolled surface such as cracks, ruptures, and laminations, and to provide assurance that only plate that is free from rejectable discontinuities is accepted for delivery.

1.2 The inspection method and acceptance criteria included in this standard shall be limited to plate of the following aluminum alloys: 1060, 1100, 3003, Alclad 3003, 3004, Alclad 3004, 5050, 5052, 5083, 5086, 5154, 5254, 5454, 5456, 5652, 6061, and Alclad 6061.

1.3 This method applies only to ultrasonic tests using pulsed longitudinal waves which are transmitted and received by a search unit containing either a single crystal or a combination of electrically interconnected multiple crystals. Ultrasonic tests employing either the through-transmission or the angle-beam techniques are not included.

1.4 This method shall be used when ultrasonic inspection as prescribed herein is required by the contract, purchase order, or referenced plate specification.

1.5 The values stated in inch-pound units are the standard. The SI values in parentheses are for information only.

1.6 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 The following documents of the issue in effect on date of material purchase form a part of this specification to the extent referenced herein:

2.1.1 *ASTM Standards:*

E 114 Practice for Ultrasonic Pulse-Echo Straight-Beam Examination by the Contact Method

E 214 Practice for Immersed Ultrasonic Examination by the Reflection Method Using Pulsed Longitudinal Waves

E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems Without the Use of Electronic Measurement Instruments

2.1.2 *Other Standard:*

ASNT Recommended Practice for Nondestructive Testing Personnel Qualification and Certification — Ultrasonic Testing Method — SNT-TC-1A.

3. Summary of Method

3.1 The plate is inspected ultrasonically by scanning one rolled surface with a beam of pulsed longitudinal waves which is oriented in a direction perpendicular to the entry surface of the plate. The ultrasound is transmitted into the plate either by the direct contact, immersion, or liquid-column coupling method. During the scan, an indication representing the first back reflec-

tion is observed on the A-scan screen of the test instrument.

3.2 When the test system sensitivity level is appropriately adjusted, a discontinuity is detected during the scan by noting an isolated indication associated with a loss of the first back reflection indication. The apparent size of the discontinuity is determined by measuring the total area in the scanned entry surface of the plate where the isolated indication and the loss of back reflection persist. The estimated discontinuity size and location are then compared with suitable acceptance criteria.

NOTE 1 — Additional information describing ultrasonic tests by the direct contact method and by the immersion method is available in Practices E 114 and E 214.

4. Significance and Use

4.1 A number of factors such as the condition of the entry and back surfaces of the plate, the inclination of the ultrasonic beam with respect to the entry surface, and the performance characteristics of the test system may cause either a reduction of isolated indications or a substantial loss of back reflection and thereby could seriously impair the reliability of the test procedure outlined in this standard.

4.2 Accurate evaluations of discontinuity size also may be limited significantly by variations in beam characteristics which exist in most search units. For this reason, discontinuity size as determined by the test procedure outlined in this method is regarded as "apparent" or "estimated" in recognition of the limited quantitative value of the measurement.

4.3 Because a large number of interacting variables in a test system can adversely influence the results of an ultrasonic test, the actual quantitative effects of detected discontinuities upon the mechanical properties of the inspected plate are difficult to establish. Consequently, this ultrasonic inspection method is not applicable as an exclusive indicator of the ultimate quality and performance of pressure vessels but provides a reliable control of plate quality to avoid failure during the forming process for fabrication of vessels.

5. Apparatus

5.1 *Test Instrument* — Any electronic device that produces pulsed longitudinal waves and displays ultrasonic reflections on an A-scan indicator when used with an appropriate search unit is satisfactory. The instrument shall provide stable, linear amplification of received pulses at a selected test frequency and shall be free from significant interface signal interference at the required sensitivity level.

5.2 *Search Unit* — The search unit recommended for this standard is the flat nonfocusing type, and contains a piezo-electric crystal which generates and receives longitudinal waves at the rated frequency when connected to the test instrument through a suitable coaxial cable. A dual-crystal search unit containing both a transmitting and a receiving crystal in one container may be used provided the test instrument will accommodate two-crystal operation and the resulting pulse-echo test is equivalent to that obtained with a search unit containing a single-crystal.

5.2.1 The total effective area of the crystal or combination of crystals in the search unit used for initial scanning shall not be less than 0.4 in.^{2} (2.6 cm^2) nor greater than 3.0 in.^{2} (19.4 cm^2).

5.2.2 The effective diameter of the round search unit used to evaluate discontinuity size shall not exceed 0.75 in. (19 mm).

NOTE 2 — For control purposes, the performance characteristics of the test instrument and search unit may be established in accordance with procedures outlined in Practice E 317.

5.3 *Tank* — For tests by the immersion method, any container is satisfactory that will facilitate the accurate, stable positioning of both the search unit and the plate to be inspected.

5.4 *Scanning Apparatus* — During the inspection procedure, the search unit is supported by any one of the following devices. The scanning apparatus shall permit measurement of both the scan distance and the index distance within ± 0.1 in. (± 2 mm).

5.4.1 *Manipulator and Bridge* — When a manipulator is used in tests by the immersion method, the manipulator shall adequately support a search tube containing a search unit and shall provide fine adjustment of angle within 1° in two vertical planes that are perpendicular to each other. The bridge shall be of sufficient strength to provide rigid support for the manipulator and shall allow smooth, accurate positioning of the search unit. Special search unit supporting fixtures may be used provided they meet the requirements prescribed for a manipulator and bridge.

5.4.2 *Liquid Coupling Nozzle* — For tests by the liquid-column coupling method, the nozzle is usually positioned manually and shall be capable of containing the couplant while rigidly supporting the search unit

with its active surface immersed in the couplant. The couplant distance shall be maintained so that the second couplant reflection is to the right of the first back reflection on the instrument cathode ray tube (CRT). The couplant path shall not vary more than $\pm\frac{1}{4}$ in. (6.4 mm) during calibration, initial scanning, and discontinuity evaluation. The recommended minimum inside dimension of the nozzle is 1.0 in. (25 mm) greater than the maximum dimension of the crystal surface in the search unit. Provisions also should be included for adjustment of search unit inclination within 1° in two vertical planes that are perpendicular to each other.

NOTE 3 — Nozzles containing either sealed or unsealed openings may be used for inspecting plate provided the test results obtained with either device are equivalent to those obtained by the immersion method.

5.4.3 *Contact Scanning Unit* — During tests by the contact method, the search unit usually is supported and positioned manually on the entry surface of the inspected plate. However, special fixtures for contact scanning may be employed provided their use ensures conformance to the requirements in this specification.

5.5 *Couplant* — Clean, deaerated water at room temperature is the recommended couplant for tests either by the immersion method or by the liquid-column coupling technique. Inhibitors or wetting agents or both may be used. For tests by the contact method, the recommended couplant is clean, light-grade oil.

NOTE 4 — Other coupling liquids may be employed for inspecting plate provided their use does not adversely affect test results.

6. Personnel Requirements

6.1 The testing operator performing the ultrasonic examination prescribed in this standard shall be qualified and certified to Level I — Ultrasonic Testing in accordance with the ASNT Recommended Practice SNT-TC-1A.

6.2 The required documentation supporting qualification and certification of ultrasonic testing operators shall be established by the certifying agency and shall be available upon request by the purchaser.

7. Condition of Plate

7.1 The entry and back surfaces of the inspected plate shall be sufficiently clean, smooth, and flat to maintain a first back reflection amplitude greater than 50% of the initial standardization amplitude while scanning an area in the plate that does not contain significant isolated ultrasonic discontinuities.

7.2 The inspected plate shall be at room temperature during the test.

8. Procedure

8.1 *Preferred Method* — The ultrasonic test may be performed by either the liquid column coupling, the direct contact, or the immersion methods. However, the immersion method is preferred.

8.1.1 Maintain the couplant distance so that the second couplant reflection is to the right of the first back reflection on the instrument cathode ray tube (CRT). The couplant path shall not vary more than $\pm\frac{1}{4}$ in. (6.4 mm) during calibration, initial scanning, and discontinuity evaluation.

8.2 *Test Frequency* — When using any of the three methods listed in 8.1, the recommended test frequency is 5.0 MHz. Other test frequencies between 2.0 MHz and 10.0 MHz may be employed when necessary to minimize possible adverse effects of plate thickness, microstructure, and test system characteristics upon test results and thereby maintain a clean, easily interpreted A-scan screen pattern throughout the inspection.

8.3 *Sensitivity Standardization* — Standardize the sensitivity level of the test system operating at the selected frequency by adjusting the instrument gain control to obtain a first back reflection amplitude of 75 ± 5% of the vertical limit exhibited by the A-scan indicator when the search unit is positioned over an area free from significant discontinuities in the plate to be inspected. During tests by either the immersion method or the liquid column coupling method, adjust the angular alignment of the search unit to obtain a maximum number of back reflections before the final sensitivity level is established.

8.4 *Scanning* — With no further adjustments of the instrument gain controls, locate the search unit over one corner of the plate to be inspected so that the edge of the crystal in the search unit is about 1 in. (25 mm) from either edge of the plate.

8.4.1 Subsequent to checking the angular alignment of the search unit with respect to the rolled entry surface to ensure a maximum first back reflection, proceed to scan the plate continuously by moving the search unit at a constant scanning rate not exceeding 12 in. (305 mm)/s from the initial starting position to

the opposite edge in a direction perpendicular to the predominant rolling direction of the plate.

8.4.2 During the scan, note the occurrence of isolated discontinuity indications and monitor the amplitude of the first back reflection by continuously observing the A-scan indicator screen.

NOTE 5 — Auxiliary monitoring devices may be employed in the test system to enhance detection reliability during the scan.

8.5 *Scan Index* — When the initial scan is completed, move the search unit over a predetermined scan index distance in a direction parallel to the predominant rolling direction of the plate and proceed with a second scan along a line parallel to the initial scanning direction while observing the test pattern on the A-scan indicator screen. Calculate the scan index distance as follows:

$$\text{Scan index distance (in.)}, S_i = 0.8 + D_s$$

$$\text{Scan index distance (mm)}, S_i = 20 + 0.7 D_s$$

where:

D_s = actual crystal diameter.

8.5.1 Continue the inspection by constantly observing the test pattern on the A-scan indicator while successively scanning the plate at a constant scanning rate in a direction perpendicular to the predominant rolling direction of the plate and indexing the search unit through the index distance calculated in 8.5.

8.5.2 During the inspection procedure, check the test system sensitivity standardization periodically by noting the amplitude of the first back reflection when the search unit is repositioned over the reference area of the plate and by adjusting the instrument gain control as required to maintain the sensitivity standardization specified previously in 8.3.

8.6 *Scanning Rate* — When the screen pattern on the A-scan indicator is monitored visually by the test operator during the inspection, the scanning rate shall not be greater than 12 in./s.

NOTE 6 — Scanning rates greater than 12 in./s may be employed if auxiliary monitoring apparatus is used to maintain adequate detection reliability.

8.7 *Detection of Discontinuities* — When an isolated ultrasonic indication of amplitude greater than 30% of the A-scan vertical limit is encountered or when the first back reflection indication decreases to an amplitude less than 5% of the vertical limit at any time during the inspection procedure, stop the scan and angulate the search unit to obtain a maximum isolated indication and to determine that the loss of back reflection is not caused by misalignment of the search unit with respect to the plate.

8.7.1 To ensure that the loss of back reflection is not caused by surface interference, check the condition of both the entry and back surfaces of the plate at the location where a substantial (95% or greater) loss of back reflection occurs.

8.7.2 Either a maximized isolated ultrasonic indication exhibiting an amplitude greater than 50% of the amplitude of the initial first back reflection used for standardization, or a substantial loss of the first back reflection indication not attributable to either search unit misalignment or surface interference, is an indication of an internal discontinuity.

NOTE 7 — Isolated indications occurring midway between the entry surface indication and the first back reflection may cause a second indication at the location of the first back reflection on the A-scan screen. When this condition is verified by checking the multiple back reflection pattern, a complete loss of the first back reflection can be assumed.

8.8 *Estimation of Discontinuity Size* — Note the location of the search unit where the scan was stopped when either an isolated indication or a loss of back reflection was observed.

8.8.1 Using a search unit containing a crystal of effective diameter no greater than 0.75 in. (19 mm), make an evaluation scan of an entire 6-in. (152-mm) square area which is centered around the point on the plate entry surface where the scan was discontinued. The recommended index distance for this evaluation is as follows:

$$S_i \text{ (in. or mm)} = 0.7 D_s$$

where:

D_s = actual diameter of the search unit crystal.

8.8.2 To determine the apparent size of the discontinuity, mark each location corresponding to the center of the search unit on the plate entry surface where a 95 ± 5% loss of first back reflection is observed or where the isolated indication exhibits an amplitude equal to 50 ± 5% of the amplitude of the initial first back reflection established during the standardization procedure outlined in 8.3.

8.8.3 Continue to mark the location of the search unit at each point where either or both of the discontinuity conditions specified in paragraph 8.8.2 are observed. The entire discontinuity shall be outlined even if it extends beyond the original 6-in. (152-mm) square evaluation scan area.

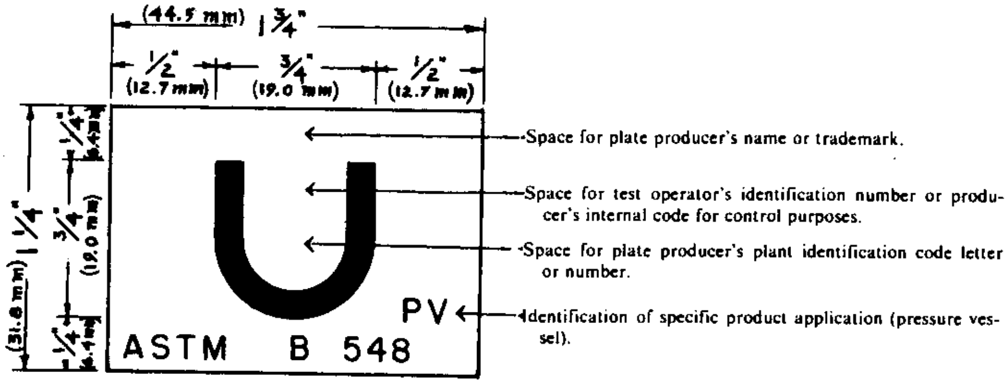


FIG. 1 STAMP FOR IDENTIFYING ACCEPTABLE PLATE

8.8.4 The estimated discontinuity size is the area defined by the boundary consisting of successive marks as established by this procedure.

NOTE 8 — Automatic recording devices may be used to establish the estimated size of a discontinuity provided the recorded results are equivalent to those obtained by the procedure presented in 8.8.

8.9 When the estimated size of a detected discontinuity is determined, return the search unit to the original stopping position and continue the initial scan to complete the inspection.

9. Acceptance Standards

9.1 Upon completing the inspection procedure, measure the longest dimension of each marked area representing a detected discontinuity. Also, when an engineering drawing showing the part to be fabricated from the plate is supplied, compare the locations of the discontinuities with the dimensions on the drawing.

9.2 If the longest dimension of the marked area representing a discontinuity causing a complete loss of back reflection (95% or greater) exceeds 1.0 in. (25 mm), the discontinuity is considered to be significant and the plate shall be subject to rejection.

9.3 If the length of the marked area representing a discontinuity causing an isolated ultrasonic indication without a complete loss of back reflection (95% or greater) exceeds 3.0 in. (76 mm), the discontinuity is considered to be significant and the plate shall be subject to rejection.

9.4 If each of two marked areas representing two adjacent discontinuities causing isolated ultrasonic indications without a complete loss of back reflection (95% or greater) is longer than 1.0 in., and if they are located within 3.0 in. of each other, the proximity between the two discontinuities is considered to be significant, and the plate shall be subject to rejection.

NOTE 9 — A template containing a 1.0-in. diameter hole and a 3.0-in. diameter hole is a convenient device for rapidly establishing the significance of discontinuities. If the discontinuities described in 9.2 and 9.3 cannot be totally enclosed within either the 1.0-in. diameter circle or the 3.0-in. diameter circle, respectively, then the plate containing such discontinuities shall be subject to rejection. Similarly, if any portions of two adjacent discontinuities greater than 1.0 in. in length as in accordance with 9.4 appear within the 3.0-in. diameter circle, the plate shall be subject to rejection.

9.5 A plate containing significant discontinuities of rejectable size shall be acceptable if it is established by the purchaser that the discontinuities will be removed from the plate by machining during the subsequent fabrication process.

9.6 Upon specific consent of the purchaser, a plate with significant discontinuities may be accepted if repaired by welding.

10. Report

10.1 When required by the purchaser, a report shall be prepared and shall include the date of test and a list of parameters including the type (model number) of instrument and search unit, the test method, frequency, and the couplant employed for the inspection.

10.2 Preparation of a drawing showing the location of all significant discontinuities in the inspected plate is recommended when the ultimate rejection or acceptance of the plate is to be determined by negotiation between the manufacturer and the purchaser.

10.3 The identification of an acceptable plate is desirable and is recommended. For this purpose, a suitable stamp should be employed to indicate conformance to this ultrasonic standard. The recommended stamp for identifying acceptable plate is shown in Fig. 1.

STANDARD PRACTICE FOR ULTRASONIC PULSE-ECHO STRAIGHT-BEAM EXAMINATION BY THE CONTACT METHOD

SE-114

(Identical with ASTM Specification E 114-95)

1. Scope

1.1 This practice covers ultrasonic examination of materials by the pulse-echo method using straight-beam longitudinal waves introduced by direct contact of the search unit with the material being examined.

1.2 This practice shall be applicable to development of an examination procedure agreed upon by the users of the document.

1.3 The values stated in inch-pound units are to be regarded as the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems Without the Use of Electronic Measurement Instruments

E 543 Practice for Evaluating Agencies That Perform Nondestructive Testing

E 1316 Terminology for Nondestructive Examinations

2.2 *ASNT Standards:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

ANSI/ASNT CP-189 ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *Military Standard:*

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification (Eddy Current, Liquid Penetrant, Magnetic Particle, Radiographic and Ultrasonic)

3. Terminology

3.1 Refer to Terminology E 1316 for definitions of terms used in this practice.

4. Basis of Application

4.1 *Purchaser-Supplier Agreements* — The following items require agreement between the using parties for this practice to be used effectively:

4.1.1 *Qualification of Nondestructive Testing Agencies* — Agreement is required as to whether the nondestructive testing agency, as defined in Practice E 543, must be formally evaluated and qualified to perform the examination. If such evaluation and qualification is specified, a documented procedure such as Practice E 543 shall be used as the basis for evaluation.

4.1.2 *Personnel Qualification* — Nondestructive testing (NDT) personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, MIL-STD-410, or a similar document. The practice or standard used and its applicable revision shall be specified in the contractual agreement between the using parties.

4.1.3 *Extent of Examination* — The extent of the examination shall be determined by agreement of the using parties.

4.1.4 *Time of Examination* — The time of examination shall be determined by agreement of the using parties.

4.1.5 *Interpretation Criteria* — The criteria by which the ultrasonic signals and part acceptability will be evaluated and shall be determined by agreement of the using parties.

5. Significance and Use

5.1 A series of electrical pulses is applied to a piezoelectric element (transducer) which converts these pulses to mechanical energy in the form of pulsed waves at a nominal frequency. This transducer is mounted in a holder so it can transmit the waves into the material through a suitable wear surface and couplant. The assembly of transducer, holder, wearface, and electrical connector comprise the search unit.

5.2 Pulsed energy is transmitted into materials, travels in a direction normal to the contacted surface, and is reflected back to the search unit by discontinuity or boundary interfaces which are parallel or near parallel to the contacted surface. These echoes return to the search unit, where they are converted from mechanical to electrical energy and are amplified by a receiver. The amplified echoes (signals) are usually presented in an A-scan display, such that the entire round trip of pulsed energy within the resolution of the system may be indicated along the horizontal baseline of the display by vertical deflections corresponding to echo amplitudes from each interface, including those from intervening discontinuities. By adjustment of the sweep (range) controls, this display can be expanded or contracted to obtain a designated relation between the displayed signals and the material reflectors from which the signal originates. Thus a scaled distance to a discontinuity and its displayed signal becomes a true relationship. By comparison of the displayed discontinuity signal amplitudes to those from a reference standard, both location and estimated discontinuity size may be determined. Discontinuities having dimensions exceeding the size of the sound beam can also be estimated by determining the amount of movement of a search unit over the examination surface where a discontinuity signal is maintained.

NOTE 1 — When determining the sizes of discontinuities by either of these two practices, only the area of the discontinuity which reflects energy to the search unit is determined.

5.3 Types of information that may be obtained from the pulsed-echo straight-beam practice are as follows:

5.3.1 Apparent discontinuity size (Note 2) by comparison of the signal amplitudes from the test piece to the amplitudes obtained from a reference standard.

5.3.2 Depth location of discontinuities by calibrating the horizontal scale of the A-scan display.

5.3.3 Material properties as indicated by the relative sound attenuation or velocity changes of compared items.

5.3.4 The extent of bond and unbond (or fusion and lack of fusion) between two ultrasonic conducting materials if geometry and materials permit.

NOTE 2 — The term "apparent" is emphasized since true size depends on orientation, composition, and geometry of the discontinuity and equipment limitations.

6. Apparatus

6.1 Complete ultrasonic apparatus shall include the following:

6.1.1 *Instrumentation* — The ultrasonic instrument shall be capable of generating, receiving, and amplifying high-frequency electrical pulses at such frequencies and energy levels required to perform a meaningful examination and to provide a suitable readout.

6.1.2 *Search Units* — The ultrasonic search units shall be capable of transmitting and receiving ultrasound in the material at the required frequencies and energy levels necessary for discontinuity detection. Typical search unit sizes usually range from $\frac{1}{8}$ in. (3.2 mm) in diameter to $1\frac{1}{8}$ in. (28.6 mm) in diameter with both smaller and larger sizes available for specific applications. Search units may be fitted with special shoes for appropriate applications. Special search units encompassing both a transmitter and a receiver as separate piezoelectric elements can be utilized to provide some degree of improved resolution near the examination surface.

6.1.3 *Couplant* — A couplant, usually a liquid or semi-liquid, is required between the face of the search unit and the examination surface to permit or improve the transmittance of ultrasound from the search unit into the material under test. Typical couplants include water, cellulose gel, oil, and grease. Corrosion inhibitors or wetting agents or both may be used. Couplants must be selected that are not detrimental to the product or the process. The couplant used in calibration should be used for the examination. During the performance of a contact ultrasonic examination, the couplant layer between search unit and examination material must be

TABLE 1
SUGGESTED VISCOSITIES — OIL COUPLANTS

Approximate Surface Roughness Average (Ra), μin. (μm)	Equivalent Couplant Viscosity, Weight Motor Oil
5–100 (0.1–2.5)	SAE 10
50–200 (1.3–5.1)	SAE 20
100–400 (2.5–10.2)	SAE 30
250–700 (6.4–17.8)	SAE 40
Over 700 (18–)	cup grease

Note — The table is a guide only and is not meant to exclude the use of a particular couplant that is found to work satisfactorily on a particular surface.

maintained such that the contact area is held constant while maintaining adequate couplant thickness. Lack of couplant reducing the effective contact area or excess couplant thickness will reduce the amount of energy transferred between the search unit and the examination piece. These couplant variations in turn result in examination sensitivity variations.

6.1.3.1 The couplant should be selected so that its viscosity is appropriate for the surface finish of the material to be examined. The examination of rough surfaces generally requires a high viscosity couplant. The temperature of the material's surface can change the couplant's viscosity. As an example, in the case of oil and greases, see Table 1.

6.1.3.2 At elevated temperatures as conditions warrant, heat resistant coupling materials such as silicone oils, gels, or greases should be used. Further, intermittent contact of the search unit with the surface or auxiliary cooling of the search unit may be necessary to avoid temperature changes that affect the ultrasonic wave characteristics of the search unit. At higher temperatures, certain couplants based on inorganic salts or thermoplastic organic materials, high temperature delay materials, and search units that are not damaged by high temperatures may be required.

6.1.3.3 Where constant coupling over large areas is needed, as in automated examination, or where severe changes in surface roughness are found, other couplants such as liquid gap coupling will usually provide a better examination. In this case, the search unit does not contact the examination surface but is separated by a distance of about 0.2 in. (0.5 mm) filled with couplant. Liquid flowing through the search unit fills the gap. The flowing liquid provides the coupling path and has the additional advantage of cooling the search unit if the examination surface is hot.

6.1.3.4 An alternative means of direct contact coupling is provided by the wheel search unit. The search unit is mounted at the required angle to a stationary axle about which rotates a liquid-filled flexible tire. A minimum amount of couplant provides ultrasonic transmission into the examination surface since the elastic tire material is in rolling contact and conforms closely to the surface.

6.1.4 *Reference Standards* — The production item itself may be an adequate standard using the height of the back wall echo for reference. For more quantitative information, machined artificial reflectors (discontinuities) or charts representing distance-amplitude relationships of known reflector sizes for a particular search unit and material may be used for calibration. These artificial reflectors may be in the form of flat-bottom holes, side-drilled holes, or slots. An alternate method of fabricating a reference standard may be the introduction of known discontinuities during the fabrication process of a production item or other convenient configuration. The surface finish of the reference standard should be similar to the surface finish of the production item (or corrected; see 7.3). The reference standard material and the production material should be acoustically similar (in velocity and attenuation). The reference standard selected shall be used by the examiner as the basis for signal comparisons.

7. Calibration of Equipment

7.1 If quantitative information is to be obtained, vertical or horizontal linearity or both should be checked in accordance with Practice E 317 or another procedure approved by the users of the document. An acceptable linearity performance may be agreed upon by the users of the document.

7.2 Prior to examination, calibrate the system in accordance with the product specification.

7.3 Where the surface finishes of the reference standard and the production item do not match, or where there is an acoustic difference between the standard and the production item, an attenuation correction should be made to compensate for the difference. The attenuation correction is accomplished by noting the difference between signals received from the same reference reflector (that is, back reflection) in the basic calibration (reference) block and in the production material, and correcting for this difference.

7.4 It should be recognized that near-field effects may cause sensitivity inconsistencies when searching

for inhomogeneities smaller than the effective beam diameter. Suitable delay line search units or other means such as inspecting from both sides of the item may be considered where the application warrants fine scrutiny. When performing examinations in the far-field, it is recommended that compensation be made for the acoustic attenuation of the test material with respect to a certain reference standard. This compensation may be accomplished with multiple depth reference reflectors, electronically, with attenuation curves drawn on the face of the A-scan display, or with charts for distance-amplitude relationships of known reflectors. For optimum examination performance, compensations should be made for both near- and far-field effects.

7.5 Unless otherwise specified, the initial pulse and at least one back reflection shall appear on the A-scan display while examining for discontinuities in materials having parallel surfaces. The total number of back reflections depends upon equipment, geometry and material type, information desired, or operator preference. Reduction of the back reflection during scanning is indicative of increased attenuation or sound scattering discontinuities provided that front and back surface roughness and parallelism of the production piece are approximately the same as that of the standard. For nonparallel surfaces, the time trace of the display shall be calibrated by using standards that include the maximum thickness of the production item being examined.

7.6 For bond/unbond (fusion/lack of fusion) examinations, a reference standard should be used similar to the production item being examined containing areas representing both bonded (fused) and unbonded (lack of fusion) conditions, if geometry and material permit.

7.7 Calibration with respect to reference standards should be periodically checked to ensure that the ultrasonic system calibration is not changing. As a minimum, the calibration shall be checked each time there is a change of operators, when search units are changed, when new batteries are installed, when equipment operating from one power source is changed to another power source, or when improper operation is suspected.

8. Procedure

8.1 When ultrasonic examinations are performed for the detection or sizing of discontinuities, or both, reflectors not perpendicular to the ultrasonic beam may be detected at reduced amplitudes, with a distorted envelope depending upon the reflector area, whether it is curved or planar, whether it is smooth or rough, perhaps with reflecting facets. Reflector characteristics may also cause rapid shifts in apparent depth as the search unit approaches or moves away from the low amplitude indication. Another effect of these reflectors is the loss of back reflection which occurs when the discontinuity lies directly between the search unit and the back surface. Reflectors detectable due to any of the foregoing phenomena cannot be sized solely on signal amplitude but require special corrections for search unit and flaw characteristics.

8.2 *Examination Surface* — Surfaces shall be uniform and free of loose scale and paint, discontinuities such as pits or gouges, weld splatter, dirt, or other foreign matter which affect examination results. Tightly adhering paint, scale, or coatings do not necessarily need to be removed for examining if they present uniform attenuation characteristics. The examination surface must be adequate to permit ultrasonic examination at the sensitivity specified. If needed, surfaces may be ground, sanded, wire brushed, scraped, or otherwise prepared for examining purposes. Curved surfaces, either concave or convex, may be examined; however, the calibration system should compensate for the effective change in search unit transmitting area between the reference standard and production item. If practical, the reference standard should have the same geometry as the item being examined.

8.3 *Search Unit* — Select a suitable search unit size and frequency after consideration of the acoustic characteristics of material to be examined, the geometry of the production item, and the minimum size and type of discontinuity to be detected. The higher the frequency selected, the higher the resolving capability accompanied with a decrease in penetrating power; conversely, the lower the frequency used, the greater the penetrating power with decreasing resolving capability. Factors limiting the use of higher frequencies are the equipment and the material properties. The limiting use of lower frequencies is the loss in sensitivity level for the examination. Various types of straight-beam search units are available offering advantages for specific applications. The above statements should be considered when choosing the search unit size, type, and frequency. When delay materials are used in the search unit, the calibration and examination surface temperatures should be within 25°F (14°C) to avoid large attenuation and velocity differences.

NOTE 3 — The largest diameter and highest frequency search units yielding desired results should be used for maximum resolution and good beam directivity.

8.4 *Scanning* — Scanning may be either continuous or intermittent, depending upon the geometry, application, and requirements of the part being examined. For continuous scanning, the search unit indexing must be adequate to provide 100% coverage, at uniform examination sensitivity, of the area being examined. Adjust scanning speed or instrument repetition rate or both to permit detection of the smallest discontinuities referenced in the specification and to allow the recording or signaling device to function.

8.4.1 *Manual Scanning* — Hold the search unit in the hand and move over the surface of the production piece.

8.4.2 *Automated Scanning* — The search unit is held by a suitable fixed device and either the production piece moves or is held stationary while the search unit moves mechanically along some predetermined path. For automated scanning, monitor coupling between the search unit and part either electronically or visually to ensure proper examination sensitivity.

8.5 During the evaluation of indications, maintain the same relative sensitivities between the reference standard and the production item. Make an evaluation of ultrasonic indications after response reflections from discontinuities are maximized by search unit manipulation. Map discontinuity extremities larger than the sound beam. A recommended method for mapping, on the surface of the production piece, the apparent size (that is, the reflecting surface seen by the search unit) of discontinuities larger than the search unit is by the half-amplitude method. Position the search unit over the discontinuity for maximum signal response and move in one direction until the signal drops rapidly to the baseline on the A-scan display. Then return the search unit to the position where the signal was half the amplitude that it had at the point where the indication began to drop rapidly to the baseline. At this point the center of the search unit should approximately coincide with the edge of the discontinuity. Repeat this procedure for other directions as necessary to outline the discontinuity on the surface. Search units of other frequencies and sizes may be used for mapping to obtain greater accuracy. Special consideration should be given to discontinuities when the signal amplitude drops to half the maximum amplitude or less, and remains at the lower level over extended distances (for example, more than half the search unit diameter).

NOTE 4 — For rounded surfaces, geometry must be considered when using this method.

9. Examination Data Record

9.1 The following data should be recorded as a minimum for future reference at the time of each examination:

9.1.1 Part number identification,

9.1.2 Operator's name and level (if certified),

9.1.3 Instrument description, make, model, and serial number,

9.1.4 Setup — Couplant, cable type and length, manual/automatic scanning,

9.1.5 Search unit description — Type, size, frequency, special shoes,

9.1.6 Reference standards (and calibration data required to duplicate the examination),

9.1.7 Indication information as specified by the applicable specification, or results of the examination (number, classification, and location of discontinuities). For bond/unbond (fusion/lack of fusion) examinations the extent of unbond (lack of fusion) or bond (fusion) should be reported.

10. Interpretation of Results

10.1 Advance agreement should be reached by users of this document as applicable regarding the interpretation of the results of the examinations and how they shall be recorded. All discontinuities having signals that exceed the rejection level as defined by the material specification, drawing, or purchase order shall be rejected unless it is determined from the machine part drawing that the rejectable discontinuities will not remain in the finished part.

11. Report

11.1 The report shall include the information agreed upon by users of this document.

12. Keywords

12.1 contact; examination; nondestructive testing; pulse-echo; straight-beam; ultrasonic

STANDARD PRACTICE FOR ULTRASONIC INSPECTION OF METAL PIPE AND TUBING

SE-213

(Identical with ASTM Specification E 213-98)

1. Scope

1.1 This practice covers a procedure for detecting discontinuities in metal pipe and tubing using pulse-reflection ultrasonic contact or immersion angle beam techniques. Artificial discontinuities consisting of longitudinal reference notches are employed as the primary means of standardizing the ultrasonic system. If transverse as well as longitudinal examination is desired, a procedure for employing transverse notches is provided.

1.2 This practice is intended for use with tubular products having outside diameters approximately $\frac{1}{2}$ in. (12.7 mm) and larger, provided that the examination parameters comply with and satisfy the requirements of Section 12. These procedures have been used successfully for smaller sizes, however, and may be specified upon contractual agreement between the using parties.

NOTE 1: **Cautions** — Exercise caution when examining pipe or tubes near or below the $\frac{1}{2}$-in. specified limit. Certain combinations of search unit size, frequency, *thin* wall thicknesses, and small diameters could cause generation of unwanted sound waves that may produce erroneous test results.

1.3 This practice does not establish acceptance criteria; they must be specified by the using party or parties.

1.4 The values stated in inch-pound units are to be regarded as standard. The SI equivalents are in parentheses and may be approximate.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 543 Practice for Evaluating Agencies That Perform Nondestructive Testing

E 1316 Terminology for Nondestructive Examinations

2.2 *ASNT Documents:*

Recommended Practice SNT-TC-1A for Nondestructive Testing Personnel Qualification and Certification

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *Military Standard:*

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification

3. Terminology

3.1 *Definitions* — For definitions of terms used in this practice, see Terminology E 1316.

4. Summary of Practice

4.1 A pulsed ultrasonic angle beam by either the surface contact or immersion method shall be used. Figure 1 illustrates the characteristic angle beam sound entry into the pipe wall for both contact and immersion testing using a single search unit.

NOTE 2 — Immersion test method may include tanks, wheel search units, or systems that use liquid streams.

4.2 Variations of the single search unit method using multiple search units with the same or various angles and special gating are sometimes desirable and may be necessary for efficient examination of thicker wall material.

5. Significance and Use

5.1 The purpose of this practice is to outline a procedure for detecting and locating significant discontinuities such as pits, voids, inclusions, cracks, splits, and the like, by the ultrasonic pulse-reflection method.

6. Basis of Application

6.1 The following are items that must be decided upon by the using party or parties.

6.1.1 Size and type of tubing to be examined.

6.1.2 Extent of examination, that is, scanning in one or both circumferential directions, scanning in one or both axial directions, weld zone only if welded, pitch of feed helix during scanning, etc.

6.1.3 The point(s) in the manufacturing process at which the material will be examined.

6.1.4 Surface condition.

6.1.5 Maximum time interval between equipment standardization checks, if different from that described in 13.2.

6.1.6 Type, dimensions, location, method of manufacture, and number of artificial discontinuities to be placed on the reference standard.

6.1.7 Method(s) for measuring dimensions of artificial discontinuities and tolerance limits if different than specified in Section 11.

6.1.8 Criteria for reportable and rejectable indications (that is, acceptance criteria).

6.1.9 Reexamination of repaired/reworked items is not addressed in this standard and if required shall be specified in the contractual agreement.

6.1.10 Requirements for permanent records of the response from each tube, if applicable.

6.1.11 Contents of testing report.

6.1.12 Operator qualifications and certification, if required.

6.1.13 Qualification of nondestructive agencies. If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in E 543. The applicable edition of E 543 shall be specified in the contractual agreement.

6.1.14 Level of personnel qualification (see 7.1).

7. Personnel Qualification

7.1 If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, MIL-STD-410, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

8. Surface Condition

8.1 All surfaces shall be clean and free of scale, dirt, grease, paint, or other foreign material that could interfere with interpretation of test results. The methods used for cleaning and preparing the surfaces for ultrasonic examination shall not be detrimental to the base metal or the surface finish. Excessive surface roughness or scratches can produce signals that interfere with the test.

9. Apparatus

9.1 The instruments and accessory equipment shall be of the pulse-reflection type and shall be capable of distinguishing the reference notches described in Section 11 to the extent required in the standardization procedure described in Section 12. Figure 1 illustrates the refraction of sound in the pipe or tube wall, and the circumferential direction of ultrasonic energy propagation used to detect longitudinal notches.

10. Couplant

10.1 A liquid couplant such as water, oil, or glycerin, capable of conducting ultrasonic vibrations between the transducer and the pipe or tube being tested shall be used. Rust inhibitors, softeners, and wetting agents may be added to the couplant. The couplant liquid with all additives should not be detrimental to the surface condition of the pipe or tube, and shall wet the surface of the material to provide adequate coupling efficiency.

NOTE 3 — In contact testing, some couplants result in better ultrasonic transmission when the tubing is precoated several hours before the test.

11. Reference Standards

11.1 A reference standard of a convenient length shall be prepared from a length of pipe or tube of the same nominal diameter, wall thickness, material, surface finish, and heat treatment as the material to be examined. The reference pipe or tube shall be free of discontinuities or other conditions producing indications that can interfere with detection of the reference notches.

11.2 Longitudinal (axial) reference notches shall be introduced on the outer and inner surfaces of the standard.

NOTE 4 — For sizes below $\frac{1}{4}$-in. inner diameter, the ratio of the outer diameter to wall thickness must be taken into consideration.

11.3 If two or more reference notches are placed on the same end of the reference standard, they shall be separated sufficiently (circumferentially or axially or both) to preclude interference and interpretation difficulties.

11.4 All upset metal, burrs, etc., adjacent to the reference notches shall be removed.

11.5 The notch dimensions, which are length, depth, and width (and for V-notches, the included angle) must be decided upon by the using party or parties. Figure 2 illustrates the common notch configurations and the dimensions to be measured (Note 5). Reflection amplitudes from V-, square-, and U-shaped notches of comparable dimensions may vary widely depending on the angle, frequency, and vibrational mode of the interrogating sound beam.

NOTE 5 — In Figure 2 (*a*), (*b*), and (*d*), the sharp corners are for ease of illustration. It is recognized that in normal machining practice, a radius will be generated.

11.5.1 The notch depth shall be an average measured from the circular tubing surface to the maximum and minimum penetration of the notch. Measurements may be made by optical, replicating, or other agreed upon techniques. Notch depth shall be within ±0.0005 in. (0.013 mm) of the specified value for notches 0.005 in. (0.13 mm) or less in depth, and within +10, −15% of the specified value for notches over 0.005 in. in depth.

NOTE 6 — For as-rolled or scaly tube surfaces, it may be necessary to modify 11.5.1. Two acceptable modifications are listed below. Modification (*a*) is preferred; however, modification (*b*) may be used unless otherwise specified.

(*a*) The circular tube surface may be smoothed or prepared in the notch area, or

(*b*) The notch depth shall be within ±0.001 in. (0.025 mm), or +10, −15% of the specified depth, whichever is greater.

11.5.2 The width of the notches shall be as small as practical, but should not exceed twice the depth.

11.6 Other types and orientations of reference discontinuities may be specified by the using party or parties.

12. Standardization of Apparatus

12.1 Using the reference standard specified in Section 11, adjust the equipment to produce clearly identifiable indications from both the inner and outer surface notches. The relative response from the inner and outer surface notches should be as nearly equal as possible. Use the lesser of the two responses to establish the rejection level. On large diameter or heavy wall pipe and tubing, if the inner and outer surface notch amplitude cannot be made equal because of test metal distance and inside diameter curvature, a separate rejection level may be established for the inner and outer surface notches.

NOTE 7 — Indication amplitude may not be proportional to notch depth.

12.2 Standardize the equipment under dynamic conditions that simulate the production examination. The pipe or tubing to be examined and the search unit assembly shall have a rotating translating motion relative to each other such that a helical scan path will be described on the outer surface of the pipe or tube. Maintain the speed of rotation and translation constant within ±10%. Axial scanning with circumferential indexing may be used to provide equivalent coverage.

12.3 The pitch of the feed helix shall be small enough to ensure 100% coverage at the test distance and sensitivity established during calibration.

13. Procedure

13.1 Unless otherwise specified, examine the pipe or tubing with the ultrasound transmitted in one circumferential direction under the identical conditions used for equipment standardization (Note 8). Examination may be required with the ultrasound transmitted in both circumferential directions (see Supplementary Requirement S1). If the examination is to be performed in both directions, conduct the standardization procedure of Section 12 in both directions.

NOTE 8 — Identical conditions include all instrument settings, mechanical motions, search unit position and alignment relative to the pipe or tube, liquid couplant, and any other factors that affect the performance of the examination.

13.2 Periodically check standardization of the equipment by passing the reference standard through the examination equipment. Make these checks prior to any examination run, prior to equipment shutdown after an examination run, and at least every 4 h during continuous equipment operation. Restandardize the equipment in accordance with Section 12 any time the equipment does not present a clearly defined, rejectable signal from both the inner and outer surface notches of the standard.

13.3 For many tubular sizes and examination arrangements, there will be a reflection from the entry surface of the pipe or tube. This signal may be observed, but not gated, as a supplement to the required checking of the reference standard to give increased assurance that the equipment is functioning properly. If such a signal does not exist, make more frequent equipment standardization checks.

13.4 In the event that the equipment does not present signals as outlined in 12.1 and 13.2, reinspect all pipe or tubing examined since the last acceptable standardization after restandardization has been accomplished.

13.5 Do not make any equipment adjustments unless the complete standardization procedure described in Section 12 is performed.

13.6 The examination shall be applied to 100% of the pipe or tubing unless otherwise specified.

NOTE 9 — Some traversing mechanisms do not allow examination of tubing ends. When this condition exists, clearly indicate the extent of this effect, per tube, in the examination report.

14. Interpretation of Results

14.1 All indications that are equal to or greater than the rejection level established during standardization as described in Section 12, or as specified by the using party or parties, shall be considered as representing defects and may be cause for rejection of the pipe or tube.

14.2 If, upon examination of the pipe or tube, no rejectable indications are detected, the material shall be considered as having passed the ultrasonic examination, except as noted in 13.4.

NOTE 10 — Rejected pipe or tubes may be reworked in a manner acceptable to the purchaser. If, upon ultrasonic reexamination of the reworked pipe or tube, no rejectable indications are detected, the material should be considered as having passed the ultrasonic examination.

NOTE 11 — Care should be exercised to ensure that reworking a pipe or tube does not change its acceptability with respect to other requirements of the material specification such as wall thickness, ovality, surface finish, length, and the like.

15. Report

15.1 When a report is required, it shall contain such information as is mutually considered adequate to document that the pipe or tubes supplied meet the requirements of this practice.

16. Keywords

16.1 angle beam; nondestructive examination; pipe; tubing; ultrasonic examination

SUPPLEMENTARY REQUIREMENTS

These requirements shall apply only when individually specified by the using party or parties. When details of these requirements are not covered herein, they may be subject to agreement by a using party.

S1. Scanning

S1.1 Scanning shall be conducted with the ultrasonic beam directed in both circumferential directions.

S2. Distance–Amplitude Correction

S2.1 A method of compensating for the reduction in ultrasonic signal amplitude as a function of test metal distance shall be employed. Details of the procedures used to establish and apply the distance–amplitude correction (DAC) curve shall be established by the using party or parties.

S3. Transverse Notches

S3.1 Instead of (or in addition to) the longitudinal notches described in Section 11, a transverse (circumfer-

ential) notch shall be introduced on the inner and outer surfaces of the reference standard. The requirements of 11.3, 11.4, and 11.5 shall apply to transverse notches.

S3.2 An independent channel of instrumentation (including search unit assembly) shall be employed for the purpose of detecting transverse discontinuities.

S3.3 When transverse notches are required, the using party or parties shall also determine whether scanning is required in one or both axial directions. Figure 3 illustrates the refraction of sound in the pipe or tube wall, and the axial propagation of ultrasonic energy to detect transverse notches.

NOTE 12 — If a requirement exists for both longitudinal and transverse notches, and scanning for each in two directions, the following three options are available:

(*a*) Each pipe or tube is passed through a single-channel examination station four times, twice in each direction,

(*b*) Each pipe or tube is passed through a two-channel examination station twice, once in each direction, or

(*c*) Each pipe or tube is passed through a four-channel examination station once.

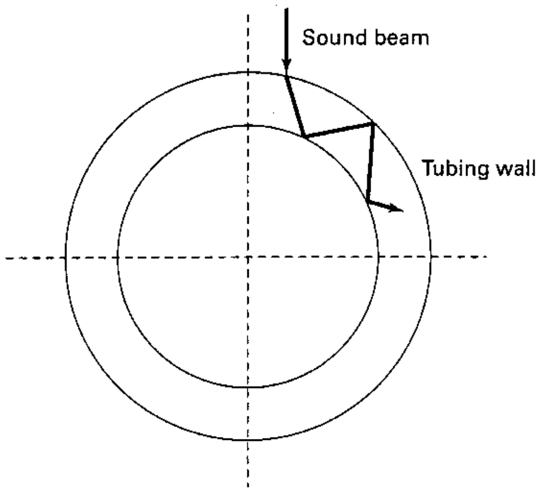


FIG. 1 CIRCUMFERENTIAL PROPAGATION OF SOUND IN TUBE WALL

S4. Recording

S4.1 A permanent record containing objective evidence of the examination results shall accompany each accepted pipe or tube. This may be in the form of a strip chart recording of the ultrasonic instrument output during the examination. It shall contain recordings of all standardizations and standardization checks and shall be annotated to provide a positive correlation between each test record and the corresponding pipe and tube.

S5. Report

S5.1 The supplier shall submit to the purchaser a report that includes at least the following information:

S5.1.1 Identification of the material by type, size, lot, heat, and the like.

S5.1.2 Identification of the examination equipment and accessories.

S5.1.3 Details of the examination technique, including examination speed, testing frequency, and end effects if any (Note 12).

S5.1.4 Description of the reference standard, including the actual (measured) dimensions of the artificial discontinuities.

S5.1.5 Description of the distance–amplitude correction procedure, if used. (See Supplementary Requirement S2.)

S5.1.6 Examination results.

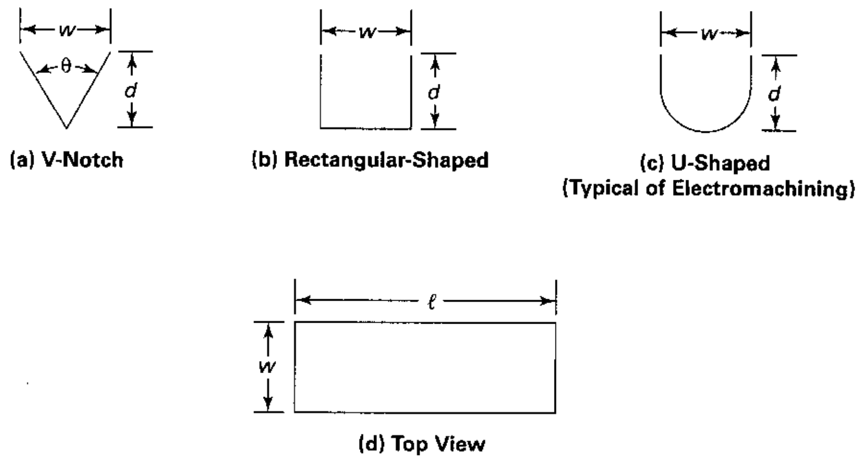


FIG. 2 COMMON NOTCH SHAPES

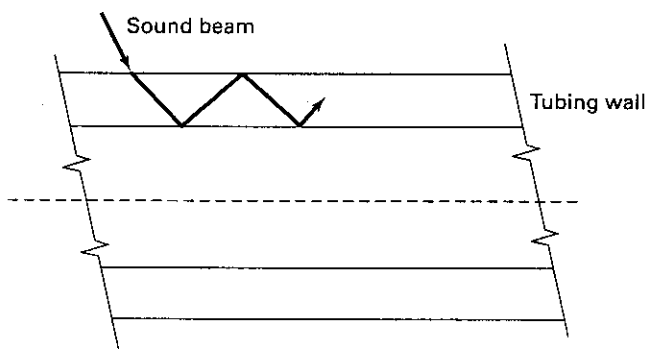


FIG. 3 AXIAL PROPAGATION OF SOUND IN TUBE WALL

STANDARD PRACTICE FOR ULTRASONIC EXAMINATION OF LONGITUDINAL WELDED PIPE AND TUBING

SE-273

(Identical with ASTM Specification E 273-93)

1. Scope

1.1 This practice describes general ultrasonic test procedures for the detection of discontinuities in the weld and adjacent heat affected zones of pipe and tubing. It is intended for tubular products having diameters ≥ 2 in. (≥ 50 mm) and wall thicknesses of $\frac{1}{8}$ to $1\frac{1}{16}$ in. (3 to 27 mm).

1.2 This practice does not establish acceptance criteria; they must be specified by the using parties.

NOTE 1—Precautions should be exercised when testing pipes or tubes near the lower specified limits. Certain combinations of search unit size, frequency, thin wall thicknesses, and small diameters could cause generation of unwanted sound waves that may produce erroneous test results.

1.3 The values stated in inch-pound units are to be regarded as the standard.

1.4 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 543 Practice for Evaluating Agencies That Perform Nondestructive Testing

E 1316 Terminology for Nondestructive Examinations

3. Terminology

3.1 *Definitions* — For definitions of terms used in this practice, see Terminology E 1316.

4. Summary of Practice

4.1 Angle projection of pulsed ultrasonic beam by either the surface contact or immersion method shall be used. Figure 1 illustrates the characteristic oblique sound entry into the pipe wall for both contact and immersion testing using a single search unit.

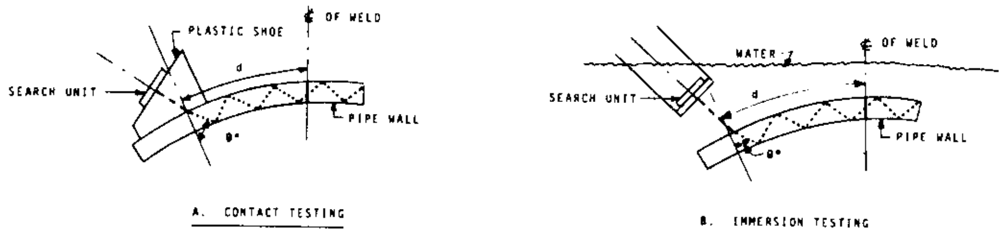
NOTE 2 — Immersion test method may include tanks, wheel search units, or bubbler systems.

4.2 Variations of the single search unit method using multiple search units with the same or various angles and special gating are sometimes desirable and may be necessary for efficient examination of thicker wall material.

5. Apparatus

5.1 The instruments and accessory equipment shall be capable of producing, receiving, amplifying, and displaying electrical pulses at frequencies and pulse rates deemed necessary by the using parties. They shall be capable of distinguishing the reference reflectors described in Section 7 to the extent required in the calibration procedure outlined in Section 8.

5.2 For pulse echo test systems, the contact or immersion search units should produce ultrasonic waves that travel in the pipe or tube wall at a refracted angle of from 35° to 70° and perpendicular to the weld seam.



NOTE—θ = 35° through 70°.

FIG. 1 ANGLE PROJECTION OF ULTRASONIC WAVE

For pitch/catch or through transmission test systems, orientation of the entry sound beam other than perpendicular to the weld seam may be required.

5.3 *Couplant* — A liquid such as water, oil, glycerin, etc., capable of conducting ultrasonic vibrations from the transducer to the pipe or tube shall be used. Rust inhibitors, softeners, and wetting agents may be added to the couplant. The couplant liquid with all additives should not be detrimental to the surface condition of the pipe or tubing and should wet the surface. In the testing of electric-resistance-welded pipe, water-soluble oil used in cooling the pipe serves as a satisfactory couplant.

5.4 *Distance Amplitude Compensation* — The use of electronic methods to compensate for attenuation losses as a function of ultrasonic metal travel distance may be employed.

6. Basis of Application

6.1 The following are items that require decision for use of this practice:

6.1.1 Acceptance criteria.

6.1.2 Type, dimension, and number of reference reflectors to be placed in the reference standard.

6.1.3 Standardization of test sensitivity intervals.

6.1.4 Operator qualifications.

6.1.5 Qualification of NDT agency (as defined in Practice E 543), if required. Practice E 543 may be used for this agency qualification.

6.1.6 Test frequency.

6.1.7 Pulse repetition rate.

6.1.8 Sound beam orientation and number of beams used.

6.1.9 Procedure and use of distance amplitude compensation.

6.1.10 Reporting of test results.

7. Personnel Qualification

7.1 The ultrasonic examination shall be performed by qualified personnel. Qualification shall be based on a documented program that certifies personnel capable of conducting ultrasonic weld examinations.

8. Reference Standards

8.1 A reference standard, of sufficient length to allow verification of system calibration, shall be prepared from a length of pipe or tubing of the same nominal diameter and wall thickness, material, surface finish, and nominal heat treatment as the material to be examined. The pipe or tube selected for this purpose shall be free of discontinuities or other abnormal conditions that can cause interference with the detection of the reference reflectors. The reference reflectors shall be selected to ensure uniform coverage of the weld at the sensitivity levels prescribed. The reference reflectors most commonly used will consist of machined notches and drilled holes as described in paragraph 8.2. All upset metal, burrs, etc., adjacent to the reference reflectors, shall be removed.

8.1.1 *Electric Resistance-Welded or Butt-Welded Pipe* — Reference reflectors may be placed in the weld seam or in the pipe body and parallel to the weld seam. When longitudinal notches are used as reference reflectors, they shall be placed on the outer and inner surfaces of the reference standard and separated by some distance to ensure that the response from one reflector does not interfere with that from the other.

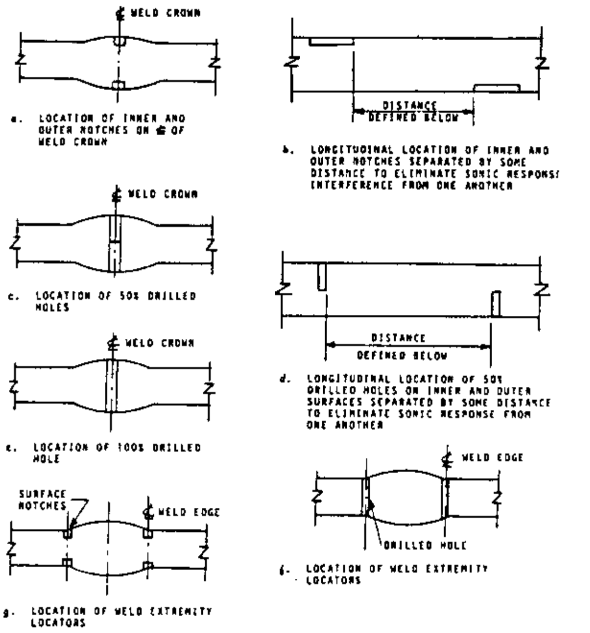


FIG. 2 TYPICAL NOTCH LOCATIONS FOR FUSION WELDED PIPE

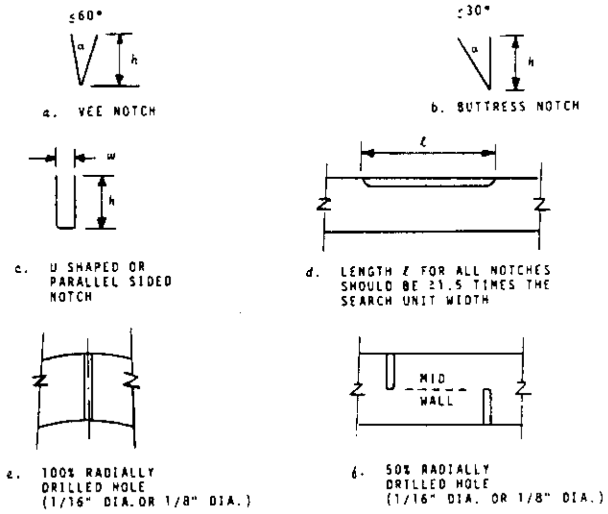


FIG. 3. COMMON REFERENCE REFLECTORS

8.1.2 *Fusion-Welded Pipe* — The reference reflectors shall be placed in the weld. When longitudinal notches are used as reference reflectors, they shall be placed in the crown of the fusion-weld bead as shown in Fig. 2(*a*). In fusion-welded pipe containing both inside and outside surface weld beads, a longitudinal notch reference reflector shall be placed in the weld-bead crown on both the outside and inside surfaces.

8.1.2.1 When drilled holes are employed, they shall be drilled radially from both the outside and inside surfaces through 50% of the wall thickness at the weld-bead crown and separated by some distance that guarantees a distinct and separate response from each one [see Figs. 2(*c*) and 2(*d*)]. A hole drilled radially 100% through the pipe wall may be used instead of the 50% drilled hole [see Fig. 2(*e*)].

8.1.2.2 Additional reflectors may be used to define weld extremities. Holes shall be drilled radially 100% through the pipe wall at the weld edges. As an alternative, longitudinal notches shall be placed at the edges of each weld [see Fig. 2(*f*)]. The weld-edge drilled holes or notches shall be separated by some distance to ensure that the response from one reflector does not interfere with that from another [see Fig. 2(*g*)]. The weld-edge reflectors are solely for the purpose of defining the position of the weld extremities and are not to be used for amplitude standardization.

8.2 The notch dimension of length, decided depth, width, and for Figs. 3(*a*) and 3(*b*) the included angle α must be decided upon by the using party or parties. Figure 3 illustrates the commonly accepted notch configurations and the dimensions to be measured.

8.2.1 The notch depth (h) shall be measured from the adjacent surface to its maximum and minimum penetration. Measurements may be made by optical, replicating or mechanical, or other techniques. Notch depth is commonly specified as a percent of nominal wall thickness with typical values being 10, 12½, or 20%. A ±15% tolerance is allowable on notch depths.

8.2.2 The length of the notch is considered to be the dimension where the depth of 8.2.1 is satisfied. It is preferred that the notch length (l) be ≥ 1.5 times the transducer element size.

8.2.3 The width (w) of the notch has negligible effect on calibration and is not a critical dimension.

8.2.4 Typical diameters for drilled holes are $\frac{1}{16}$ in. (1.6 mm) and $\frac{1}{8}$ in. (3.2 mm).

9. Standardization of Test Sensitivity

9.1 Using the reference standard specified in 8.1, the equipment shall be adjusted to produce readily distinguished and clearly identifiable indications from both the inner and outer reference reflectors. The relative

response to the inner and outer reflectors shall be as near equal as possible. The lesser of the two responses shall be used as the acceptance level.

NOTE 3 — Adjustment of water path, adjustment of distance (*d*) in Fig. 1 and angulation of the beam have been used to achieve equality.

9.2 The test sensitivity shall be standardized and adjusted to produce clearly identifiable indications from both the outer and inner reference reflectors when the reference standard is scanned in a manner simulating the production examination of the pipe or tubing.

9.3 The equipment shall be adjusted to produce clearly identifiable responses from the weld-edge reflector and the reference reflector when the reference standard is scanned in a manner simulating the production examination of the pipe or tubing.

10. Examination Procedure

10.1 All surfaces shall be clean from scale, dirt, burrs, slag, spatter, or other conditions that will interfere with the test results.

10.2 Move the pipe or tubing past the search unit with the weld in a fixed position with respect to the search unit. Movement of the search unit with respect to a stationary pipe is satisfactory. During examination, maintain distance (*d*) and angle θ in Fig. 1 and the water path for immersion testing as determined during adjustment of the test sensitivity.

10.3 Certain testing systems using multiple search units or multiple beam transducers compensate for distance (*d*) changes and do not require strict adherence to the maintenance of this dimension during examination.

10.4 Periodically check the test sensitivity of the equipment by running the reference standard through the examination system. Make these checks prior to any pipe or tubing examination, prior to equipment shutdown after examination and at least every four hours during continuous equipment operation. Any time the equipment does not present a clearly defined signal within 10% of that obtained when the test sensitivity was established, readjust the equipment in accordance with Section 8.

10.5 In the event that the equipment presents a signal less than 10% below the standardization level, reexamine, when standardization has been accomplished, all pipe and tubing examined subsequent to the last preceding acceptable standardization.

11. Interpretation of Results

11.1 All indications that are equal to or greater than the reference signals established during standardization as described in Section 9, or as specified in Section 6, shall be considered as representing defects that may be cause for rejection of the pipe or tube.

11.2 If upon examination of the pipe or tube, no rejectable indications are detected, the material shall be considered as having passed the ultrasonic examination, except as noted in 10.5.

12. Keywords

12.1 angle beam; longitudinal welded pipe; longitudinal welded tubing; nondestructive examination; ultrasonic examination

STANDARD PRACTICE FOR MEASURING THICKNESS BY MANUAL ULTRASONIC PULSE-ECHO CONTACT METHOD

SE-797

(Identical with ASTM E 797-95)

1. Scope

1.1 This practice provides guidelines for measuring the thickness of materials using the contact pulse-echo method at temperatures not to exceed 200°F (93°C).

1.2 This practice is applicable to any material in which ultrasonic waves will propagate at a constant velocity throughout the part, and from which back reflections can be obtained and resolved.

1.3 The values stated in either inch-pound or SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems Without the Use of Electronic Measurement Instruments

E 494 Practice for Measuring Ultrasonic Velocity in Materials

E 1316 Terminology for Nondestructive Examinations

2.2 *ASNT Document:*

Nondestructive Testing Handbook, 2nd Edition, Vol 7

3. Terminology

3.1 *Definitions* — For definitions of terms used in this practice, refer to Terminology E 1316.

4. Summary of Practice

4.1 Thickness (T), when measured by the pulse-echo ultrasonic method, is a product of the velocity of sound in the material and one half the transit time (round trip) through the material.

$$T = \frac{Vt}{2}$$

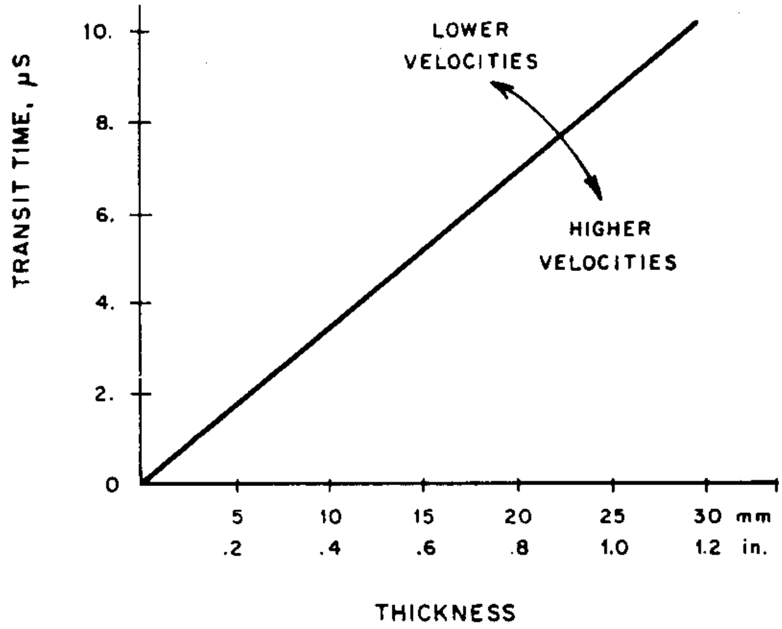
where:

T = thickness,
V = velocity, and
t = transit time.

4.2 The pulse-echo ultrasonic instrument measures the transit time of the ultrasonic pulse through the part.

4.3 The velocity in the material under test is a function of the physical properties of the material. It is usually assumed to be a constant for a given class of materials. Its approximate value can be obtained from Table X3.1 in Practice E 494 or from the *Nondestructive Testing Handbook,* or it can be determined empirically.

4.4 One or more reference blocks are required having known velocity, or of the same material to be tested, and having thicknesses accurately measured and in the range of thicknesses to be measured. It is generally desirable that the thicknesses be "round numbers" rather than miscellaneous odd values. One block should have a thickness value near the maximum of the



NOTE – Slope of velocity conversion line is approximately that of steel.

FIG. 1 TRANSIT TIME/THICKNESS RELATIONSHIP

range of interest and another block near the minimum thickness.

4.5 The display element [CRT (cathode ray tube), meter, or digital display] of the instrument must be adjusted to present convenient values of thickness dependent on the range being used. The control for this function may have different names on different instruments, including *range, sweep, material calibrate,* or *velocity.*

4.6 The timing circuits in different instruments use various conversion schemes. A common method is the so-called time/analog conversion in which the time measured by the instrument is converted into a proportional dc voltage which is then applied to the readout device. Another technique uses a very high-frequency oscillator that is modulated or gated by the appropriate echo indications, the output being used either directly to suitable digital readouts or converted to a voltage for other presentation. A relationship of transit time versus thickness is shown graphically in Fig. 1.

5. Significance and Use

5.1 The techniques described provide indirect measurement of thickness of sections of materials not exceeding temperatures of 200°F (93°C). Measurements are made from one side of the object, without requiring access to the rear surface.

5.2 Ultrasonic thickness measurements are used extensively on basic shapes and products of many materials, on precision machined parts, and to determine wall thinning in process equipment caused by corrosion and erosion.

5.3 Recommendations for determining the capabilities and limitations of ultrasonic thickness gages for specific applications can be found in the cited references.

6. Apparatus

6.1 *Instruments* — Thickness-measurement instruments are divided into three groups: (*1*) Flaw detectors with CRT readout, (*2*) Flaw detectors with CRT and direct thickness readout, and (*3*) Direct thickness readout.

6.1.1 Flaw detectors with CRT readouts display time/amplitude information in an A-scan presentation. Thickness determinations are made by reading the distance between the zero-corrected initial pulse and first-returned echo (back reflection), or between multi-

ple-back reflection echoes, on a calibrated base line of a CRT. The base line of the CRT should be adjusted for the desired thickness increments.

6.1.2 Flaw detectors with numeric readout are a combination pulse ultrasound flaw detection instrument with a CRT, and additional circuitry that provides digital thickness information. The material thickness can be electronically measured and presented on a digital readout. The CRT provides a check on the validity of the electronic measurement by revealing measurement variables, such as internal discontinuities, or echo-strength variations, which might result in inaccurate readings.

6.1.3 Thickness readout instruments are modified versions of the pulse-echo instrument. The elapsed time between the initial pulse and the first echo or between multiple echoes is converted into a meter or digital readout. The instruments are designed for measurement and direct numerical readout of specific ranges of thickness and materials.

6.2 *Search Units* — Most pulse-echo type search units (straight-beam contact, delay line, and dual element) are applicable if flaw detector instruments are used. If a thickness readout instrument has the capability to read thin sections, a highly damped, high-frequency search unit is generally used. High-frequency (10 MHz or higher) delay line search units are generally required for thicknesses less than about 0.6 mm (0.025 in.). Measurements of materials at high temperatures require search units specially designed for the application. When dual element search units are used, their inherent nonlinearity usually requires special corrections for thin sections (see Fig. 2.) For optimum performance, it is often necessary that the instrument and search units be matched.

6.3 *Calibration Blocks*—The general requirements for appropriate calibration blocks are given in 4.4, 7.1.3, 7.2.2.1, 7.3.2, and 7.4.3. Multi-step blocks that may be useful for these calibration procedures are described in Appendix XI (Figs. X1.1 and X1.2).

7. Procedure—Calibration and Adjustment of Apparatus

7.1 *Case I—Direct Contact, Single-Element Search Unit:*

7.1.1 *Conditions*—The display start is synchronized to the initial pulse. All display elements are linear. Full thickness is displayed on CRT.

7.1.2 Under these conditions, we can assume that the velocity conversion line effectively pivots about the origin (Fig. 1). It may be necessary to subtract the wear-plate time, requiring minor use of delay control. It is recommended that test blocks providing a minimum of two thicknesses that span the thickness range be used to check the full-range accuracy.

7.1.3 Place the search unit on a test block of known thickness with suitable couplant and adjust the instrument controls (material calibrate, range, sweep, or velocity) until the display presents the appropriate thickness reading.

7.1.4 The readings should then be checked and adjusted on test blocks with thickness of lesser value to improve the overall accuracy of the system.

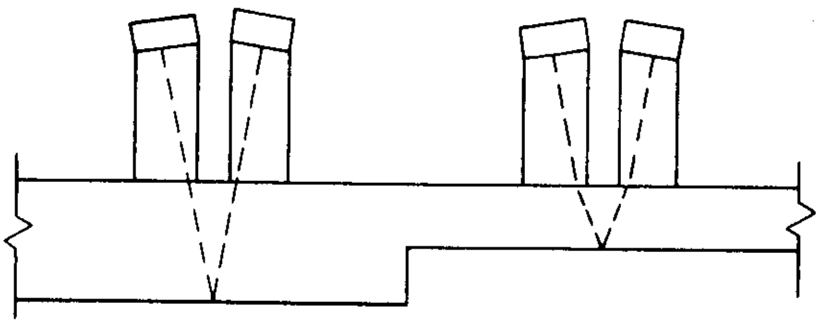
7.2 *Case II—Delay Line Single-Element Search Unit:*

7.2.1 *Conditions*—When using this search unit, it is necessary that the equipment be capable of correcting for the time during which the sound passes through the delay line so that the end of the delay can be made to coincide with zero thickness. This requires a so-called "delay" control in the instrument, or automatic electronic sensing of zero thickness.

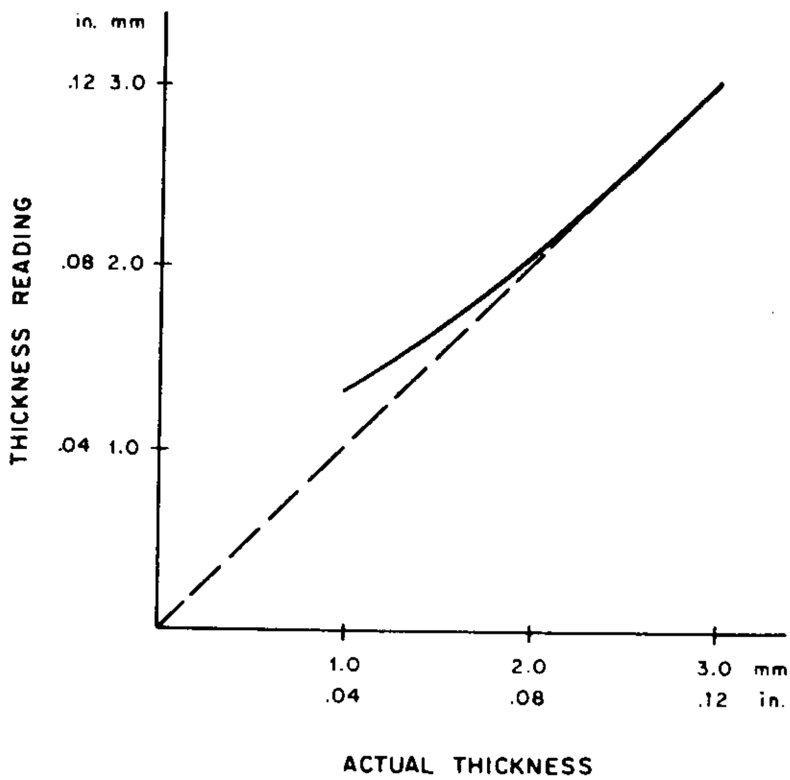
7.2.2 In most instruments, if the material calibrate circuit was previously adjusted for a given material velocity, the delay control should be adjusted until a correct thickness reading is obtained on the instrument. However, if the instrument must be completely calibrated with the delay line search unit, the following technique is recommended:

7.2.2.1 Use at least two test blocks. One should have a thickness near the maximum of the range to be measured and the other block near the minimum thickness. For convenience, it is desirable that the thickness should be "round numbers" so that the difference between them also has a convenient "round number" value.

7.2.2.2 Place the search unit sequentially on one and then the other block, and obtain both readings. The difference between these two readings should be calculated. If the reading thickness difference is less than the actual thickness difference, place the search unit on the thicker specimen, and adjust the material calibrate control to expand the thickness range. If the reading thickness difference is greater than the actual thickness difference, place the search unit on the thicker specimen, and adjust the material calibrate control to decrease the thickness range. A certain amount of over correction is usually recommended. Reposition the



(*a*) Proportional sound path increases with decrease in thickness.



(*b*) Typical reading error values

FIG. 2 DUAL TRANSDUCER NONLINEARITY

search unit sequentially on both blocks, and note the reading differences while making additional appropriate corrections. When the reading thickness differential equals the actual thickness differential, the material thickness range is correctly adjusted. A single adjustment of the delay control should then permit correct readings at both the high and low end of the thickness range.

7.2.3 An alternative technique for delay line search units is a variation of that described in 7.2.2. A series of sequential adjustments are made, using the "delay" control to provide correct readings on the thinner test block and the "range" control to correct the readings on the thicker block. Moderate over-correction is sometimes useful. When both readings are "correct" the instrument is adjusted properly.

7.3 *Case III—Dual Search Units:*

7.3.1 The method described in 7.2 (Case II) is also suitable for equipment using dual search units in the thicker ranges, above 3 mm (0.125 in.). However, below those values there is an inherent error due to the Vee path that the sound beam travels. The transit time is no longer linearly proportional to thickness, and the condition deteriorates toward the low thickness end of the range. The variation is also shown schematically in Fig. 2(*a*). Typical error values are shown in Fig. 2(*b*).

7.3.2 If measurements are to be made over a very limited range near the thin end of the scale, it is possible to calibrate the instrument with the technique in Case II using appropriate thin test blocks. This will produce a correction curve that is approximately correct over that limited range. Note that it will be substantially in error at thicker measurements.

7.3.3 If a wide range of thicknesses is to be measured, it may be more suitable to calibrate as in Case II using test blocks at the high end of the range and perhaps halfway toward the low end. Following this, empirical corrections can be established for the very thin end of the range.

7.3.4 For a direct-reading panel-type meter display, it is convenient to build these corrections into the display as a nonlinear function.

7.4 *Case IV—Thick Sections:*

7.4.1 *Conditions*—For use when a high degree of accuracy is required for thick sections.

7.4.2 Direct contact search unit and initial pulse synchronization are used. The display start is delayed as described in 7.4.4. All display elements should be linear. Incremental thickness is displayed on the CRT.

7.4.3 Basic calibration of the sweep will be made as described in Case I. The test block chosen for this calibration should have a thickness that will permit calibrating the full-sweep distance to adequate accuracy, that is, about 10 mm (0.4 in.) or 25 mm (1.0 in.) full scale.

7.4.4 After basic calibration, the sweep must be delayed. For instance, if the nominal part thickness is expected to be from 50 to 60 mm (2.0 to 2.4 in.), and the basic calibration block is 10 mm (0.4 in.), and the incremental thickness displayed will also be from 50 to 60 mm (2.0 to 2.4 in.), the following steps are required. Adjust the delay control so that the fifth back echo of the basic calibration block, equivalent to 50 mm (2.0 in.), is aligned with the 0 reference on the CRT. The sixth back echo should then occur at the right edge of the calibrated sweep.

7.4.5 This calibration can be checked on a known block of the approximate total thickness.

7.4.6 The reading obtained on the unknown specimen must be added to the value delayed off screen. For example, if the reading is 4 mm (0.16 in.), the total thickness will be 54 mm (2.16 in.).

8. Technical Hazards

8.1 Dual search units may also be used effectively with rough surface conditions. In this case, only the first returned echo, such as from the bottom of a pit, is used in the measurement. Generally, a localized scanning search is made to detect the minimum remaining wall.

8.2 *Material Properties*—The instrument should be calibrated on a material having the same acoustic velocity and attenuation as the material to be measured. Where possible, calibration should be confirmed by direct dimensional measurement of the material to be examined.

8.3 *Scanning*—The maximum speed of scanning should be stated in the procedure. Material conditions, type of equipment, and operator capabilities may require slower scanning.

8.4 *Geometry:*

8.4.1 Highest accuracy can be obtained from materials with parallel or concentric surfaces. In many cases, it is possible to obtain measurements from materials

with nonparallel surfaces. However, the accuracy of the reading may be limited and the reading obtained is generally that of the thinnest portion of the section being interrogated by the sound beam at a given instant.

8.4.2 Relatively small diameter curves often require special techniques and equipment. When small diameters are to be measured, special procedures including additional specimens may be required to ensure accuracy of setup and readout.

8.5 High-temperature materials, up to about 540°C (1000°F), can be measured with specially designed instruments with high temperature compensation, search unit assemblies, and couplants. Normalization of apparent thickness reading for elevated temperatures is required. A rule of thumb often used is as follows: The apparent thickness reading obtained from steel walls having elevated temperatures is high (too thick) by a factor of about 1% per 55°C (100°F). Thus, if the instrument was calibrated on a piece of similar material at 20°C (68°F), and if the reading was obtained with a surface temperature of 460°C (860°F), the apparent reading should be reduced by 8%. This correction is an average one for many types of steel. Other corrections would have to be determined empirically for other materials.

8.6 *Instrument*—Time base linearity is required so that a change in the thickness of material will produce a corresponding change of indicated thickness. If a CRT is used as a readout, its horizontal linearity can be checked by using Practice E 317.

8.7 *Back Reflection Wavetrain*—Direct-thickness readout instruments read the thickness at the first half cycle of the wavetrain that exceeds a set amplitude and a fixed time. If the amplitude of the back reflection from the measured material is different from the amplitude of the back reflection from the calibration blocks, the thickness readout may read to a different half cycle in the wavetrain, thereby producing an error. This may be reduced by:

8.7.1 Using calibration blocks having attenuation characteristics equal to those in the measured material or adjusting back reflection amplitude to be equal for both the calibrating blocks and measured material.

8.7.2 Using an instrument with automatic gain control to produce a constant amplitude back reflection.

8.8 *Readouts*—CRT displays are recommended where reflecting surfaces are rough, pitted, or corroded.

8.8.1 Direct-thickness readout, without CRT, presents hazards of misadjustment and misreading under certain test conditions, especially thin sections, rough corroded surfaces, and rapidly changing thickness ranges.

8.9 *Calibration Standards*—Greater accuracy can be obtained when the equipment is calibrated on areas of known thickness of the material to be measured.

8.10 Variations in echo signal strength may produce an error equivalent to one or more half-cycles of the RF frequency, dependent on instrumentation characteristics.

9. Procedure Requirements

9.1 In developing the detailed procedure, the following items should be considered:

9.1.1 Instrument manufacturer's operating instructions.

9.1.2 Scope of materials/objects to be measured.

9.1.3 Applicability, accuracy requirements.

9.1.4 Definitions.

9.1.5 Requirements.

9.1.5.1 Personnel.

9.1.5.2 Equipment.

9.1.5.3 Procedure qualification.

9.1.6 Procedure.

9.1.6.1 Measurement conditions.

9.1.6.2 Surface preparation and couplant.

9.1.6.3 Calibration and allowable tolerances.

9.1.6.4 Scanning parameters.

9.1.7 Report.

9.1.7.1 Procedure used.

9.1.7.2 Calibration record.

9.1.7.3 Measurement record.

10. Report

10.1 Record the following information at the time of the measurements and include it in the report:

10.1.1 Inspection procedure.

10.1.1.1 Type of instrument.

10.1.1.2 Calibration blocks, size and material type.

10.1.1.3 Size, frequency, and type of search unit.

10.1.1.4 Scanning method.

10.1.2 Results.

10.1.2.1 Maximum and minimum thickness measurements.

10.1.2.2 Location of measurements.

10.1.3 Personnel data, certification level.

11. Keywords

11.1 contact testing; nondestructive testing; pulse-echo; thickness measurement; ultrasonics

APPENDIX

(Nonmandatory Information)

X1. TYPICAL MULTI-STEP THICKNESS GAGE CALIBRATION BLOCKS

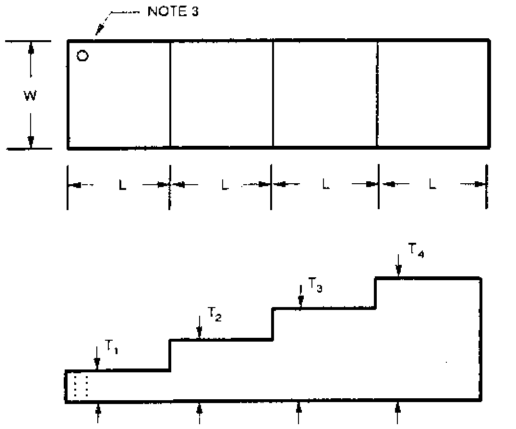


TABLE OF DIMENSIONS

	U.S. Customary Block, in.		Metric Block 4A, mm		Metric Block 4B, mm	
Legend	Dimension	Tolerance	Dimension	Tolerance	Dimension	Tolerance
T_1	0.250	0.001	6.25	0.02	5.00	0.02
T_2	0.500	0.001	12.50	0.02	10.00	0.02
T_3	0.750	0.001	18.75	0.02	15.00	0.02
T_4	1.000	0.001	25.00	0.02	20.00	0.02
L	0.75	0.02	20.0	0.5	20.0	0.5
W	0.75	0.05	20.0	1.0	20.0	1.0

NOTE 1—Material to be as specified.
NOTE 2—Surface finish: "T" faces Ra 32 μin. (0.8 μm) max.
Other surfaces Ra 63 μin. (1.6 μm) max.
NOTE 3—Location for optional 1/16 in. (1.5 mm) diameter through hole used for block support during plating; center 1/16 in. (1.5 mm) from block edges.
NOTE 4—All "T" dimensions to be after any required plating or anodizing.
NOTE 5—In order to prevent sharp edges, minimize plating buildup, or remove in-service nicks and burrs, block edges may be smoothed by beveling or rounding, provided that the corner treatment does not reduce the edge dimension by more than 0.020 in. (0.5 mm).

FIG. X1.1 TYPICAL FOUR-STEP THICKNESS CALIBRATION BLOCKS

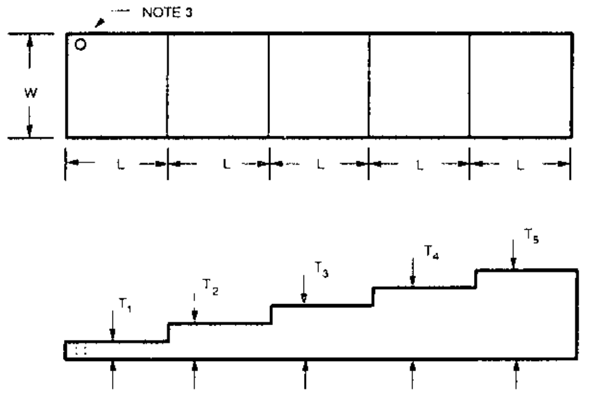


TABLE OF DIMENSIONS

	U.S. Customary Block, in.		Metric Block 5A, mm		Metric Block 5B, mm	
Legend	Dimension	Tolerance	Dimension	Tolerance	Dimension	Tolerance
T_1	0.100	0.001	2.50	0.02	2.00	0.02
T_2	0.200	0.001	5.00	0.02	4.00	0.02
T_3	0.300	0.001	7.50	0.02	6.00	0.02
T_4	0.400	0.001	10.00	0.02	8.00	0.02
T_5	0.500	0.001	12.50	0.02	10.00	0.02
L	0.75	0.02	20.0	0.5	20.00	0.5
W	0.75	0.05	20.0	1.0	20.00	1.0

NOTE 1—Material to be as specified.
NOTE 2—Surface finish: "T" faces Ra 32 μin. (0.8 μm) max.
Other surfaces Ra 63 μin. (1.6 μm) max.
NOTE 3—Location for optional 1/16 in. (1.5 mm) diameter through hole used for block support during plating; center 1/16 in. (1.5 mm) from block edges.
NOTE 4—All "T" dimensions to be after any required plating or anodizing.
NOTE 5—In order to prevent sharp edges, minimize plating buildup, or remove in-service nicks and burrs, block edges may be smoothed by beveling or rounding, provided that the corner treatment does not reduce the edge dimension by more than 0.020 in. (0.5 mm).

FIG. X1.2 TYPICAL FIVE-STEP THICKNESS CALIBRATION BLOCKS

01

ARTICLE 24
LIQUID PENETRANT STANDARDS

STANDARD TEST METHOD FOR SULFUR IN PETROLEUM PRODUCTS (GENERAL BOMB METHOD)

SD-129

(Identical with ASTM D 129-95)
(This specification is available in SI Units only.)

1. Scope

1.1 This test method covers the determination of sulfur in petroleum products, including lubricating oils containing additives, additive concentrates, and lubricating greases that cannot be burned completely in a wick lamp. The test method is applicable to any petroleum product sufficiently low in volatility that it can be weighed accurately in an open sample boat and containing at least 0.1% sulfur.

NOTE 1 — This test method is not applicable to samples containing elements that give residues, other than barium sulfate, which are insoluble in dilute hydrochloric acid and would interfere in the precipitation step. These interfering elements include iron, aluminum, calcium, silicon, and lead which are sometimes present in greases, lube oil additives, or additive oils. Other acid insoluble materials that interfere are silica, molybdenum disulfide, asbestos, mica, etc. The test method is not applicable to used oils containing wear metals, and lead or silicates from contamination. Samples that are excluded can be analyzed by Test Method D 1552.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* See 3.2 for specific precautionary directions incorporated in the test method.

2. Referenced Documents

2.1 *ASTM Standards:*

D 1193 Specification for Reagent Water

D 1552 Test Method for Sulfur in Petroleum Products (High-Temperature Method)

E 144 Practice for Safe Use of Oxygen Combustion Bombs

3. Summary of Test Method

3.1 The sample is oxidized by combustion in a bomb containing oxygen under pressure. The sulfur, as sulfate in the bomb washings, is determined gravimetrically as barium sulfate.

3.2 Warning — *Strict adherence to all of the provisions prescribed hereafter ensures against explosive rupture of the bomb, or a blow-out, provided the bomb is of proper design and construction and in good mechanical condition. It is desirable, however, that the bomb be enclosed in a shield of steel plate at least 13 mm thick, or equivalent protection be provided against unforseeable contingencies.*

4. Apparatus and Materials

4.1 *Bomb,* having a capacity of not less than 300 mL, so constructed that it will not leak during the test and that quantitative recovery of the liquids from the bomb may be achieved readily. The inner surface of the bomb may be made of stainless steel or any other material that will not be affected by the combustion process or products. Materials used in the bomb assembly, such as the head gasket and lead-wire insulation, shall be resistant to heat and chemical action, and shall not undergo any reaction that will affect the sulfur content of the liquid in the bomb.

4.2 *Sample Cup,* platinum, 24 mm in outside diameter at the bottom, 27 mm in outside diameter at the top, 12 mm in height outside, and weighing 10 to 11 g.

4.3 *Firing Wire,* platinum, No. 26 B & S gage, 0.41 mm (16 thou), 27 SWG, or equivalent.

NOTE 2: **Caution** — The switch in the ignition circuit shall be of a type which remains open, except when held in closed position by the operator.

4.4 *Ignition Circuit,* capable of supplying sufficient current to ignite the cotton wicking or nylon thread without melting the wire. The current shall be drawn from a step-down transformer or from a suitable battery.

4.5 *Cotton Wicking or Nylon Sewing Thread,* white.

5. Reagents and Materials

5.1 *Purity of Reagents* — Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

5.2 *Purity of Water* — Unless otherwise indicated, references to water shall mean water as defined by Type II or III of Specification D 1193.

5.3 *Barium Chloride Solution* (85 g/litre) — Dissolve 100 g of barium chloride dihydrate ($BaCl_2 \cdot 2H_2O$) in distilled water and dilute to 1 litre.

5.4 *Bromine Water (saturated).*

5.5 *Hydrochloric Acid* (sp gr 1.19) — Concentrated hydrochloric acid (HCl).

5.6 *Oxygen,* free of combustible material and sulfur compounds, available at a pressure of 41 kgf/cm^2 (40 atm).

5.7 *Sodium Carbonate Solution* (50 g/litre) — Dissolve 135 g of sodium carbonate decahydrate ($Na_2CO_3 \cdot 10H_2O$) or its equivalent weight in distilled water and dilute to 1 litre.

5.8 *White Oil, USP, or Liquid Paraffin, BP, or equivalent.*

6. Procedure

6.1 *Preparation of Bomb and Sample* — Cut a piece of firing wire 100 mm in length. Coil the middle section (about 20 mm) and attach the free ends to the terminals. Arrange the coil so that it will be above and to one side of the sample cup. Insert between two loops of the coil a wisp of cotton or nylon thread of such length that one end will extend into the sample cup. Place about 5 mL of Na_2CO_3 solution in the bomb (Note 3) and rotate the bomb in such a manner that the interior surface is moistened by the solution. Introduce into the sample cup the quantities of sample and white oil (Notes 5 and 6) specified in the following table, weighing the sample to the nearest 0.2 mg (when white oil is used, stir the mixture with a short length of quartz rod and allow the rod to remain in the sample cup during the combustion).

NOTE 3 — After repeated use of the bomb for sulfur determinations, a film may be noticed on the inner surface. This dullness can be removed by periodic polishing of the bomb. A satisfactory method for doing this is to rotate the bomb in a lathe at about 300 rpm and polish the inside surface with emery polishing papers Grit No. $^2/_0$, or equivalent paper, coated with a light machine oil to prevent cutting, and then with a paste of grit-free chromic oxide and water. This procedure will remove all but very deep pits and put a high polish on the surface. Before the bomb is used it shall be washed with soap and water to remove oil or paste left from the polishing operation.

NOTE 4: **Caution** — Do not use more than 1.0 g total of sample and white oil or other low sulfur combustible material or more than 0.8 g if the IP 12 bomb is used.

Sulfur Content, %	Weight of Sample, g	Weight of White Oil, g
5 or under	0.6 to 0.8	0.0
Over 5	0.3 to 0.4	0.3 to 0.4

NOTE 5 — Use of sample weights containing over 20 mg of chlorine may cause corrosion of the bomb. To avoid this, it is recommended that for samples containing over 2% chlorine, the sample weight be based on the chlorine content as given in the following table:

Chlorine Content, %	Weight of Sample, g	Weight of White Oil, g
2 to 5	0.4	0.4
Over 5 to 10	0.2	0.6
Over 10 to 20	0.1	0.7
Over 20 to 50	0.05	0.7

NOTE 6 — If the sample is not readily miscible with white oil, some other low sulfur combustible diluent may be substituted. However, the combined weight of sample and nonvolatile diluent shall not exceed 1.0 g or more than 0.8 g if the IP 12 bomb is used.

6.2 *Addition of Oxygen* — Place the sample cup in position and arrange the cotton wisp or nylon thread so that the end dips into the sample. Assemble the bomb and tighten the cover securely. (**Caution** — See

Note 7.) Admit oxygen slowly (to avoid blowing the oil from the cup) until a pressure is reached as indicated in the following table:

Capacity of Bomb, ml	Minimum Gage Pressure,[A] kgf/cm^2 (atm)	Maximum Gage Pressure,[A] kgf/cm^2 (atm)
300 to 350	39 (38)	41 (40)
350 to 400	36 (35)	38 (37)
400 to 450	31 (30)	33 (32)
450 to 500	28 (27)	30 (29)

[A] The minimum pressures are specified to provide sufficient oxygen for complete combustion and the *maximum pressures represent a safety requirement.*

NOTE 7: **Caution** — Do not add oxygen or ignite the sample if the bomb has been jarred, dropped, or tilted.

6.3 *Combustion* — Immerse the bomb in a cold distilled-water bath. Connect the terminals to the open electrical circuit. Close the circuit to ignite the sample. (**Caution** — See Note 8.) Remove the bomb from the bath after immersion for at least 10 min. Release the pressure at a slow, uniform rate such that the operation requires not less than 1 min. Open the bomb and examine the contents. If traces of unburned oil or sooty deposits are found, discard the determination and thoroughly clean the bomb before again putting it in use (Note 3).

NOTE 8: **Caution** — Do not go near the bomb until at least 20 s after firing.

6.4 *Collection of Sulfur Solution* — Rinse the interior of the bomb, the oil cup, and the inner surface of the bomb cover with a fine jet of water, and collect the washings in a 600-mL beaker having a mark to indicate 75 mL. Remove any precipitate in the bomb by means of a rubber policeman. Wash the base of the terminals until the washings are neutral to the indicator methyl red. Add 10 mL of saturated bromine water to the washings in the beaker. (The volume of the washings is normally in excess of 300 mL.) Place the sample cup in a 50-mL beaker. Add 5 mL of saturated bromine water, 2 mL of HCl, and enough water just to cover the cup. Heat the contents of the beaker to just below its boiling point for 3 or 4 min and add to the beaker containing the bomb washings. Wash the sample cup and the 50-mL beaker thoroughly with water. Remove any precipitate in the cup by means of a rubber policeman. Add the washings from the cup and the 50-mL beaker, and the precipitate, if any, to the bomb washings in the 600-mL beaker. Do not filter any of the washings, since filtering would remove any sulfur present as insoluble material.

6.5 *Determination of Sulfur* — Evaporate the combined washings to 200 mL on a hot plate or other source of heat. Adjust the heat to maintain slow boiling of the solution and add 10 mL of the $BaCl_2$ solution, either in a fine stream or dropwise. Stir the solution during the addition and for 2 min thereafter. Cover the beaker with a fluted watch glass and continue boiling slowly until the solution has evaporated to a volume approximately 75 mL as indicated by a mark on the beaker. Remove the beaker from the hot plate (or other source of heat) and allow it to cool for 1 hr before filtering. Filter the supernatant liquid through an ashless, quantitative filter paper (Note 9). Wash the precipitate with water, first by decantation and then on the filter, until free from chloride. Transfer the paper and precipitate to a weighed crucible and dry (Note 10) at a low heat until the moisture has evaporated. Char the paper completely without igniting it, and finally ignite at a bright red heat until the residue is white in color. After ignition is complete, allow the crucible to cool at room temperature, and weigh.

NOTE 9 — A weighed porcelain filter crucible (Selas type) of 5 to 9-μm porosity may be used in place of the filter paper. In this case the precipitate is washed free of chloride and then dried to constant weight at 500 ± 25°C.

NOTE 10 — A satisfactory means of drying, charring, and igniting the paper and precipitate is to place the crucible containing the wet filter paper in a cold electric muffle furnace and to turn on the current. Drying, charring, and ignition usually will occur at the desired rate.

6.6 *Blank* — Make a blank determination whenever new reagents, white oil, or other low-sulfur combustible material are used. When running a blank on white oil, use 0.3 to 0.4 g and follow the normal procedure.

7. Calculation

7.1 Calculate the sulfur content of the sample as follows:

$$\text{Sulfur, weight percent} = (P - B)13.73/W$$

where:

P = grams of $BaSO_4$ obtained from sample,
B = grams of $BaSO_4$ obtained from blank, and
W = grams of sample used.

8. Report

8.1 Report the results of the test to the nearest 0.01%.

9. Precision and Bias

9.1 The precision of this test is not known to have been obtained in accordance with currently accepted guidelines (for example in Committee D-2 Research Report, "Manual on Determining Precision Data for ASTM Methods on Petroleum Products and Lubricants").

9.1.1 *Repeatability* — The difference between two test results, obtained by the same operator with the same apparatus under constant operating conditions on identical test material, would in the long run, in the normal and correct operation of the test method, exceed the following values only in one case in twenty.

9.1.2 *Reproducibility* — The difference between two single and independent results obtained by different operators working in different laboratories on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following values only in one case in twenty:

Sulfur, Weight %	Repeatability	Reproducibility
0.1 to 0.5	0.04	0.05
0.5 to 1.0	0.06	0.09
1.0 to 1.5	0.08	0.15
1.5 to 2.0	0.12	0.25
2.0 to 5.0	0.18	0.27

NOTE 11 — The precision shown in the above table does not apply to samples containing over 2% chlorine because an added restriction on the amount of sample which can be ignited is imposed.

NOTE 12 — This test method has been cooperatively tested only in the range of 0.1 to 5.0% sulfur.

NOTE 13 — The following information on the precision of this method has been developed by the Institute of Petroleum (London):

(a) Results of duplicate tests should not differ by more than the following amounts:

Repeatability	Reproducibility
$0.016\ x + 0.06$	$0.037\ x + 0.13$

where x is the mean of duplicate test results.

(b) These precision values were obtained in 1960 by statistical examination of interlaboratory test results. No limits have been established for additive concentrates.

9.2 *Bias* — Results obtained in one laboratory by Test Method D 129 on NIST Standard Reference Material Nos. 1620A, 1621C, and 1662B were found to be 0.05 mass % higher than the accepted reference values.

10. Keywords

10.1 bomb; sulfur

STANDARD TEST METHOD FOR SULFATE ION IN WATER

SD-516

(Identical with ASTM D 516-90)

1. Scope

1.1 This turbidimetric test method covers the determination of sulfate in water in the range from 1 to 40 mg/L of sulfate ion (SO_4^{--}).

1.2 This test method was used successfully with drinking, ground, and surface waters. It is the user's responsibility to ensure the validity of this test method for waters of untested matrices.

1.3 Former gravimetric and volumetric test methods have been discontinued. Refer to Appendix X1 for historical information.

1.4 *This standard does not purport to address the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1066 Practice for Sampling Steam
D 1129 Terminology Relating to Water
D 1192 Specification for Equipment for Sampling Water and Steam in Closed Conduits
D 1193 Specification for Reagent Water
D 2777 Practice for Determination of Precision and Bias of Applicable Methods of Committee D-19 on Water
D 3370 Practices for Sampling Water from Closed Conduits
E 60 Practice for Photometric and Spectrophotometric Methods for the Chemical Analysis of Metals
E 275 Practice for Describing and Measuring Performance of Ultraviolet, Visible, and Near Infrared Spectrophotometers

3. Terminology

3.1 *Definitions* — For definitions of terms used in this test method, refer to Terminology D 1129.

4. Summary of Test Method

4.1 Sulfate ion is converted to a barium sulfate suspension under controlled conditions. A solution containing glycerin and sodium chloride is added to stabilize the suspension and minimize interferences. The resulting turbidity is determined by a nephelometer, spectrophotometer, or photoelectric colorimeter and compared to a curve prepared from standard sulfate solutions.

5. Significance and Use

5.1 The determination of sulfate is important because it has been reported that when this ion is present in excess of about 250 mg/L in drinking water, it causes a cathartic action (especially in children) in the presence of sodium and magnesium, and gives a bad taste to the water.

6. Interferences

6.1 Insoluble suspended matter in the sample must be removed. Dark colors that can be compensated for in the procedure interfere with the measurement of suspended barium sulfate ($BaSO_4$).

6.2 Polyphosphates as low as 1 mg/L will inhibit barium sulfate precipitation causing a negative interference. Phosphonates present in low concentrations, depending on the type of phosphonate, will also cause a negative interference. Silica in excess of 500 mg/L

may precipitate along with the barium sulfate causing a positive interference. Chloride in excess of 5000 mg/L will cause a negative interference. Aluminum, polymers, and large quantities of organic material present in the test sample may cause the barium sulfate to precipitate nonuniformly. In the presence of organic matter certain bacteria may reduce sulfate to sulfide. To minimize the action of sulfate reducing bacteria, samples should be refrigerated at 4°C when the presence of such bacteria is suspected.

6.3 Although other ions normally found in water do not appear to interfere, the formation of the barium sulfate suspension is very critical. Determinations that are in doubt may be checked by a gravimetric method in some cases, or by the procedure suggested in Note 2.

7. Apparatus

7.1 *Photometer* — One of the following, which are given in order of preference.

7.1.1 Nephelometer or turbidimeter;

7.1.2 Spectrophotometer for use at 420 nm with light path of 4 to 5 cm;

7.1.3 Filter photometer with a violet filter having a maximum near 420 nm and a light path of 4 to 5 cm.

7.2 *Stopwatch,* if the magnetic stirrer is not equipped with an accurate timer.

7.3 *Measuring Spoon,* capacity 0.2 to 0.3 mL.

7.4 Filter photometers and photometric practices prescribed in this test method shall conform to Practice E 60; spectrophotometer practices shall conform to Practice E 275.

8. Reagents

8.1 *Purity of Reagents* — Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

8.2 *Purity of Water* — Unless otherwise indicated, references to water shall be understood to mean reagent water conforming to Specification D 1193, Type III.

8.3 *Barium Chloride* — Crystals of barium chloride ($BaCl_2 \cdot 2H_2O$) screened to 20 to 30 mesh. To prepare in the laboratory, spread crystals over a large watch glass, desiccate for 24 h, screen to remove any crystals that are not 20 to 30 mesh, and store in a clean, dry jar.

8.4 *Conditioning Reagent* — Place 30 mL of concentrated hydrochloric acid (HCl, sp gr 1.19), 300 mL reagent water, 100 mL 95% ethanol or isopropanol and 75 g sodium chloride (NaCl) in a container. Add 50 mL glycerol and mix.

8.5 *Sulfate Solution, Standard* (1 mL = 0.100 mg SO_4^{--}) — Dissolve 0.1479 g of anhydrous sodium sulfate (Na_2SO_4) in water, and dilute with water to 1 L in a volumetric flask.

9. Sampling

9.1 Collect the sample in accordance with Practice D 1066, Specification D 1192, and Practices D 3370, as applicable.

10. Calibration

10.1 Follow the procedure given in Section 11, using appropriate amounts of the standard sulfate solution prepared in accordance with 8.5 and prepare a calibration curve showing sulfate ion content in milligrams per litre plotted against the corresponding photometer readings (Note 1). Prepare standards by diluting with water 0.0, 2.0, 5.0, 10.0, 15.0, 20.0, 30.0, and 40.0 mL of standard sulfate solution to 100-mL volumes in volumetric flasks. These solutions will have sulfate ion concentrations of 0.0, 2.0, 5.0, 10.0, 15.0, 20.0, 30.0, and 40.0 mg/L (ppm), respectively.

NOTE 1 — A separate calibration curve must be prepared for each photometer and a new curve must be prepared if it is necessary to change the cell, lamp, or filter, or if any other alterations of instrument or reagents are made. Check the curve with each series of tests by running two or more solutions of known sulfate concentrations.

11. Procedure

11.1 Filter the sample if it is turbid, and adjust the temperature to between 15 and 30°C.

11.2 Pipet into a 250-mL beaker 100 mL or less of the clear sample containing between 0.5 and 4 mg of sulfate ion (Note 2). Dilute to 100 mL with water if required, and add 5.0 mL of conditioning reagent (Note 1).

NOTE 2 — The solubility of $BaSO_4$ is such that difficulty may be experienced in the determination of sulfate concentrations below about 5 mg/L (ppm). This can be overcome by concentrating the sample or by adding 5 mL of standard sulfate solution (1 mL = 0.100 mg SO_4^{--}) to the sample before diluting to 100 mL. This will add 0.5 mg SO_4 to the sample, which must be subtracted from the final result.

11.3 Mix in the stirring apparatus.

11.4 While the solution is being stirred, add a measured spoonful of $BaCl_2$ crystals (0.3 g) and begin timing immediately.

11.5 Stir exactly 1.0 min at constant speed.

NOTE 3 — The stirring should be at a constant rate in all determinations. The use of a magnetic stirrer has been found satisfactory for this purpose.

11.6 Immediately after the stirring period has ended, pour solution into the cell and measure the turbidity at 30-s intervals for 4 min. Record the maximum reading obtained in the 4-min period.

11.7 If the sample contains color or turbidity, run a sample blank using the procedure 11.2 through 11.6 without the addition of the barium chloride.

11.8 If interferences are suspected, dilute the sample with an equal volume of water, and determine the sulfate concentration again. If the value so determined is one half that in the undiluted sample, interferences may be assumed to be absent.

TABLE 1
OVERALL (S_T) AND SINGLE-OPERATOR (S_O) STANDARD DEVIATIONS AGAINST MEAN CONCENTRATION FOR INTERLABORATORY RECOVERY OF SULFATE FROM REAGENT WATER[A]

Mean Concentration ($\bar{X}$), mg/L	Standard Deviation, mg/L	
	S_T	S_O
6.6	0.5	0.1
20.4	1.0	0.4
63.7	2.5	1.3

[A] The test method is linear to 40 mg/L. Testing at the 63.9 level was accomplished through dilution as described in 11.2.

TABLE 2
OVERALL (S_T) AND SINGLE-OPERATOR (S_O) STANDARD DEVIATIONS AGAINST MEAN CONCENTRATION FOR INTERLABORATORY RECOVERY OF SULFATE FROM DRINKING, GROUND, AND SURFACE WATER[A]

Mean Concentration ($\bar{X}$), mg/L	Standard Deviation, mg/L	
	S_T	S_O
6.9	0.7	0.5
20.2	2.2	1.8
63.3	4.5	1.6

[A] The test method is linear to 40 mg/L. Testing at the 63.9 level was accomplished through dilution as described in 11.2.

12. Calculation

12.1 Convert the photometer readings obtained with the sample to milligrams per litre sulfate ion (SO_4^{--}) by use of the calibration curve described in Section 10.

13. Precision and Bias

13.1 The precision and bias data presented in this test method meet the requirements of Practice D 2777-86.

13.2 The overall and single-operator precision of the test method, within its designated range, varies with the quantity being tested according to Table 1 for reagent water and Table 2 for drinking, ground, and surface waters.

13.2.1 Seven laboratories participated in the round robin at three levels in triplicate, making a total of 21 observations at each level for reagent water and for matrix water (drinking, ground, and surface water).

13.3 Recoveries of known amounts of sulfate from reagent water and drinking, ground, and surface waters are as shown in Table 3.

13.3.1 A table for estimating the bias of the test method through its applicable concentration range can be found in Table 4.

13.3.2 These collaborative test data were obtained on reagent grade water and natural waters. For other matrices, these data may not apply.

14. Keywords

14.1 drinking water; ground water; sulfate; surface water; turbidimetric

TABLE 3
DETERMINATION OF BIAS[A]

	Amount Added, mg/L	Amount Found, mg/L	±Bias	±%Bias	Statistically Significant at 5% Level (at ± 0.05)
Reagent water	20.8	20.4	−0.4	−1.9%	No
	63.9[A]	63.7[A]	−0.2	−0.2%	No
	7.0	6.6	−0.4	−5.3%	No
Drinking, ground and surface water	20.8	20.2	−0.6	−2.7%	No
	63.9[A]	63.3[A]	−0.6	−0.9%	No
	7.0	6.9	−0.1	−1.8%	No

[A] The test method is linear to 40 mg/L. Testing at the 63.9 level was accomplished through dilution as described in 11.2.

TABLE 4
MEAN SULFATE RECOVERY AGAINST CONCENTRATION ADDED WITH OVERALL STANDARD DIVISION SHOWN FOR INTERLABORATORY EXPERIMENTAL RECOVERY OF SULFATE FROM REAGENT WATER AND DRINKING, GROUND, AND SURFACE WATER[A]

Sufate Added, mg/L	Mean Surface Recovery (X), mg/L	
	Reagent Water (S_T)	Matrix Water (S_0)
7.0	6.6 (0.5)	6.9 (0.7)
20.8	20.4 (1.0)	20.2 (2.2)
63.9	63.7 (2.5)	63.3 (4.5)

[A] The test method is linear to 40 mg/L. Testing at the 63.9 level was accomplished through dilution as described in 11.2.

APPENDIX

(Nonmandatory Information)

X1. RATIONALE FOR DISCONTINUATION OF METHODS

X1.1 *Gravimetric:*

X1.1.1 This test method was discontinued in 1988. The test method may be found in the *1988 Annual Book of ASTM Standards,* Vol 11.01. The test method was originally issued in 1938.

X1.1.2 This test method covers the determination of sulfate in water and wastewater. Samples containing from 20 to 100 mg/L sulfate may be analyzed.

X1.1.3 Sulfate is precipitated and weighted as barium sulfate after removal of silica and other insoluble matter.

X1.1.4 This test method was discontinued because there were insufficient laboratories interested in participating in another collaborative study to obtain the necessary precision and bias as required by Practice D 2777.

X1.2 *Volumetric:*

X1.2.1 This test method was discontinued in 1988. The test method may be found in the *1988 Annual Book of ASTM Standards,* Vol 11.01. The test method was originally issued in 1959 as a non-referee method, and made the primary method in the 1980 issue of Test Method D 516.

X1.2.2 This test method covers the determination of sulfate in industrial water. Samples containing from 5 to 1000 mg/L of sulfate may be analyzed.

X1.2.3 Sulfate is titrated in an alcoholic solution under controlled acid conditions with a standard barium chloride solution using thorin as the indicator.

X1.2.4 This test method was discontinued because there were insufficient laboratories interested in participating in another collaborative study to obtain the necessary precision and bias as required by Practice D 2777.

STANDARD TEST METHOD FOR CHLORINE IN NEW AND USED PETROLEUM PRODUCTS (BOMB METHOD)

SD-808

(Identical with ASTM D 808-95)

1. Scope

1.1 This test method covers the determination of chlorine in lubricating oils and greases, including new and used lubricating oils and greases containing additives, and in additive concentrates. Its range of applicability is 0.1 to 50% chlorine. The procedure assumes that compounds containing halogens other than chlorine will not be present.

1.2 The preferred units are mass percent and SI.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1193 Specification for Reagent Water

D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products

3. Summary of Test Method

3.1 The sample is oxidized by combustion in a bomb containing oxygen under pressure (**Caution** — See Note 1). The chlorine compounds thus liberated are absorbed in a sodium carbonate solution and the amount of chlorine present is determined gravimetrically by precipitation as silver chloride.

NOTE 1: (**Caution** — **Safety** — Strict adherence to all of the provisions prescribed hereinafter ensures against explosive rupture of the bomb, or a blow-out, provided the bomb is of proper design and construction and in good mechanical condition. It is desirable, however, that the bomb be enclosed in a shield of steel plate at least 13 mm ($\frac{1}{2}$ in.) thick, or equivalent protection be provided against unforseeable contingencies.

4. Significance and Use

4.1 This test method may be used to measure the level of chlorine-containing compounds in petroleum products. This knowledge can be used to predict performance or handling characteristics of the product in question.

5. Apparatus

5.1 *Bomb,* having a capacity of not less than 300 mL, so constructed that it will not leak during the test, and that quantitative recovery of the liquids from the bomb may be readily achieved. The inner surface of the bomb may be made of stainless steel or any other material that will not be affected by the combustion process or products. Materials used in the bomb assembly, such as the head gasket and lead-wire insulation, shall be resistant to heat and chemical action, and shall not undergo any reaction that will affect the chlorine content of the liquid in the bomb.

5.2 *Sample Cup,* platinum, 24 mm in outside diameter at the bottom, 27 mm in outside diameter at the top, 12 mm in height outside, and weighing 10 to 11 g.

5.3 *Firing Wire,* platinum, No. 26 B & S gage 0.41 (16 thou), 27 SWG or equivalent.

5.4 *Ignition Circuit,* capable of supplying sufficient current to ignite the nylon thread or cotton wicking without melting the wire.

5.4.1 The switch in the ignition circuit shall be of a type that remains open, except when held in closed position by the operator.

5.5 *Nylon Sewing Thread, or Cotton Wicking,* white.

5.6 *Filter Crucible,* fritted-glass, 30-mL capacity, medium porosity.

TABLE 1
QUANTITIES OF SAMPLE AND WHITE OIL

Chlorine Content, %	Weight of Sample, g	Weight of White Oil, g
2 and under	0.8	0.0
Above 2 to 5, incl	0.4	0.4
Above 5 to 10, incl	0.2	0.6
Above 10 to 20, incl	0.1	0.7
Above 20 to 50, incl	0.05	0.7

6. Reagents and Materials

6.1 *Purity of Reagents* — Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

6.2 *Purity of Water* — Unless otherwise indicated, references to water shall be understood to mean reagent water as defined by Type II or III of Specification D 1193.

6.3 *Nitric Acid* (1 + 1) — Mix equal volumes of concentrated nitric acid (HNO_3, sp gr 1.42) and water.

6.4 *Oxygen,* free of combustible material and halogen compounds, available at a pressure of 41 kgf/cm^2 (40 atmos). (**Warning** — See Note 2.)

NOTE 2: **Warning** — Oxygen vigorously accelerates combustion.

6.5 *Silver Nitrate Solution* (50 g $AgNO_3$/L) — Dissolve 50 g of silver nitrate ($AgNO_3$) in water and dilute to 1 L.

6.6 *Sodium Carbonate Solution* (50 g Na_2CO_3/L) — Dissolve 50 g of anhydrous Na_2CO_3, 58.5 g of $Na_2CO_3 \cdot H_2O$, or 135 g of $Na_2CO_3 \cdot 10\ H_2O$ in water and dilute to 1 L.

6.7 *White Oil,* refined.

7. Sampling

7.1 Take samples in accordance with the instructions in Practice D 4057.

7.2 Take care that the sample is thoroughly representative of the material to be tested and that the portion of the sample used for the test is thoroughly representative of the whole sample.

8. Procedure

8.1 *Preparation of Bomb and Sample* — Cut a piece of firing wire approximately 100 mm in length. Coil the middle section (about 20 mm) and attach the free ends to the terminals. Arrange the coil so that it will be above and to one side of the sample cup. Insert into the coil a nylon thread, or wisp of cotton, of such length that one end will extend into the sample cup. Place about 5 mL of Na_2CO_3 solution in the bomb and by means of a rubber policeman, wet the interior surface of the bomb, including the head, as thoroughly as possible. Introduce into the sample cup the quantities of sample and white oil (Notes 3 and 4) specified in Table 1 (**Caution** — Note 5), weighing the sample to the nearest 0.2 mg. (When white oil is used, stir the mixture with a short length of quartz rod and allow the rod to remain in the sample cup during the combustion.)

8.1.1 After repeated use of the bomb for chlorine determination, a film may be noticed on the inner surface. This dullness can be removed by periodic polishing of the bomb. A satisfactory method for doing this is to rotate the bomb in a lathe at about 300 rpm and polish the inside with Grit No. 2/0 or equivalent paper coated with a light machine oil to prevent cutting, and then with a paste of grit-free chromic oxide and water. This procedure will remove all but very deep pits and put a high polish on the surface. Before using the bomb wash it with soap and water to remove oil or paste left from the polishing operation. Bombs with porous or pitted surfaces should never be used because of the tendency to retain chlorine from sample to sample.

8.1.2 When the sample is not readily miscible with white oil, some other nonvolatile, chlorine-free combustible diluent may be employed in place of white

TABLE 2
GAGE PRESSURE

Capacity of Bomb, mL	Minimum Gage Pressure,[A] kgf/cm^2 (atm)	Maximum Gage Pressure,[A] kgf/cm^2 (atm)
300 to 350	39 (38)	41 (40)
350 to 400	36 (35)	38 (37)
400 to 450	31 (30)	33 (32)
450 to 500	28 (27)	30 (29)

[A] The minimum pressures are specified to provide sufficient oxygen for complete combustion, and the *maximum pressures represent a safety requirement.*

oil. However, the combined weight of sample and nonvolatile diluent shall not exceed 1 g. Some solid additives are relatively insoluble, but may be satisfactorily burned when covered with a layer of white oil.

NOTE 3 — The practice of running alternately high and low samples in chlorine content shall be avoided whenever possible. It is difficult to rinse the last traces of chlorine from the walls of the bomb and the tendency for residual chlorine to carry over from sample to sample has been observed in a number of laboratories. When a sample high in chlorine has preceded one low in chlorine content, the test on the low-chlorine sample shall be repeated and one or both of the low values thus obtained can be considered suspect if they do not agree within the limits of repeatability of this method.

NOTE 4: **Caution** — Do not use more than 1 g total of sample and white oil or other chlorine-free combustible material.

8.2 *Addition of Oxygen* — Place the sample cup in position and arrange the nylon thread, or wisp of cotton, so that the end dips into the sample. Assemble the bomb and tighten the cover securely. Admit oxygen (**Caution** — See Note 8) slowly (to avoid blowing the oil from the cup) until a pressure is reached as indicated in Table 2.

NOTE 5: **Caution** — Do not add oxygen or ignite the sample if the bomb has been jarred, dropped, or tilted.

8.3 *Combustion* — Immerse the bomb in a cold water bath. Connect the terminals to the open electrical circuit. Close the circuit to ignite the sample. Remove the bomb from the bath after immersion for at least 10 min. Release the pressure at a slow, uniform rate such that the operation requires not less than 1 min. Open the bomb and examine the contents. If traces of unburned oil or sooty deposits are found, discard the determination, and thoroughly clean the bomb before again putting it in use (8.1.1).

8.4 *Collection of Chlorine Solution* — Rinse the interior of the bomb, the sample cup, and the inner surface of the bomb cover with a fine jet of water, and collect the washings in a 600-mL beaker. Scrub the interior of the bomb and the inner surface of the bomb cover with a rubber policeman. Wash the base of the terminals until the washings are neutral to the indicator methyl red. (The volume of the washings is normally in excess of 300 mL.) Take special care not to lose any wash water.

8.5 *Determination of Chlorine* — Acidify the solution by adding HNO_3 (1 + 1) drop by drop until acid to methyl red. Add an excess of 2 mL of the HNO_3 solution. Filter through a qualitative paper [if the solution is cloudy, the presence of lead chloride ($PbCl_2$) is indicated and the solution should be brought to a boil before filtering] and collect in a second 600-mL beaker. Heat the solution to about 60°C (140°F) and, while protecting the solution from strong light, add gradually, while stirring, 5 mL of $AgNO_3$ solution. Heat to incipient boiling and retain at this temperature until the supernatant liquid becomes clear. Test to ensure complete precipitation by adding a few drops of the $AgNO_3$ solution. If more precipitation takes place, repeat the above steps which have involved heating, stirring, and addition of $AgNO_3$, as often as necessary, until the additional drops of $AgNO_3$ produce no turbidity in the clear, supernatant liquid. Allow the beaker and contents to stand in a dark place for at least an hour. Filter the precipitate by suction on a weighed fritted-glass filter crucible. Wash the precipitate with water containing 2 mL of HNO_3 (1 + 1)/L. Dry the crucible and precipitate at 110°C for 1 h. Cool in a desiccator, and weigh.

8.6 *Blank* — Make a blank determination with 0.7 to 0.8 g of white oil by following the normal procedure but omitting the sample (Notes 6 and 9). Repeat this blank whenever new batches of reagents or white oil are used. The blank must not exceed 0.03% chlorine based upon the weight of the white oil.

NOTE 6 — This procedure measures chlorine in the white oil and in the reagents used, as well as that introduced from contamination.

9. Calculation

9.1 Calculate the chlorine content of the sample as follows:

$$\text{Chlorine, mass \%} = [(P - B) \times 24.74]/W$$

where:

P = grams of AgCl obtained from the sample,
B = grams of AgCl obtained from the blank, and
W = grams of sample used.

10. Precision and Bias

10.1 The precision of this test method is not known to have been obtained in accordance with currently accepted guidelines (for example, in Committee D-2 Research Report RR:D2-1007, Manual on Determining Precision Data for ASTM Methods on Petroleum Products and Lubricants).

10.2 The precision of this test method as obtained by statistical examination of interlaboratory test results is as follows:

10.2.1 *Repeatability* — The difference between successive test results obtained by the same operator with the same apparatus under constant operating conditions on identical test material would, in the long run, in the normal and correct operation of the test method exceed the following values only in one case in twenty:

Chlorine, %	Repeatability
0.1 to 1.9	0.07
2.0 to 5.0	0.15
Above 5.0	3% of amount present

10.2.2 *Reproducibility* — The difference between two single and independent results obtained by different operators working in different laboratories on identical test material would, in the long run, in the normal and correct operation of the test method exceed the following values only in one case in twenty:

Chlorine, %	Reproducibility
0.1 to 1.9	0.10
2.0 to 5.0	0.30
Above 5.0	5% of amount present

10.3 *Bias:*

10.3.1 Cooperative data indicate that deviations of test results from the true chlorine content are of the same order of magnitude as the reproducibility.

10.3.2 It is not practicable to specify the bias of this test method for measuring chlorine because the responsible subcommittee, after diligent search, was unable to attract volunteers for an interlaboratory study.

11. Keywords

11.1 bomb; chlorine

STANDARD TEST METHOD FOR SULFUR IN PETROLEUM PRODUCTS (HIGH-TEMPERATURE METHOD)

SD-1552

(Identical with ASTM D 1552-95)

1. Scope

1.1 This test method covers three procedures for the determination of total sulfur in petroleum products including lubricating oils containing additives, and in additive concentrates. This test method is applicable to samples boiling above 177°C (350°F) and containing not less than 0.06 mass % sulfur. Two of the three procedures use iodate detection; one employing an induction furnace for pyrolysis, the other a resistance furnace. The third procedure uses IR detection following pyrolysis in a resistance furnace.

1.2 Petroleum coke containing up to 8 mass % sulfur can be analyzed.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1193 Specification for Reagent Water

D 1266 Test Method for Sulfur in Petroleum Products (Lamp Method)

D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products

3. Summary of Test Method

3.1 *Iodate Detection System* — The sample is burned in a stream of oxygen at a sufficiently high temperature to convert about 97% of the sulfur to sulfur dioxide. A standardization factor is employed to obtain accurate results. The combustion products are passed into an absorber containing an acid solution of potassium iodide and starch indicator. A faint blue color is developed in the absorber solution by the addition of standard potassium iodate solution. As combustion proceeds, bleaching the blue color, more iodate is added. The amount of standard iodate consumed during the combustion is a measure of the sulfur content of the sample.

3.2 *IR Detection System* — The sample is weighed into a special ceramic boat which is then placed into a combustion furnace at 1371°C (2500°F) in an oxygen atmosphere. Most sulfur present is combusted to SO_2 which is then measured with an infrared detector after moisture and dust are removed by traps. A microprocessor calculates the mass percent sulfur from the sample weight, the integrated detector signal, and a predetermined calibration factor. Both the sample identification number and mass percent sulfur are then printed out. The calibration factor is determined using standards approximating the material to be analyzed.

4. Significance and Use

4.1 This test method provides a means of monitoring the sulfur level of various petroleum products and additives. This knowledge can be used to predict performance, handling, or processing properties. In some cases the presence of sulfur compounds is beneficial

to the product and monitoring the depletion of sulfur can provide useful information. In other cases the presence of sulfur compounds is detrimental to the processing or use of the product.

5. Interferences

5.1 For the iodate systems, chlorine in concentrations less than 1 mass % does not interfere. The IR system can tolerate somewhat higher concentrations. Nitrogen when present in excess of 0.1 mass % may interfere with the iodate systems; the extent of such interference may be dependent on the type of nitrogen compound as well as the combustion conditions. Nitrogen does not interfere with the IR system. The alkali and alkaline earth metals, as well as zinc, phosphorus, and lead, do not interfere with either system.

6. Apparatus

6.1 *Combustion and Iodate Detection System*

6.1.1 *Furnaces* — Two major types are available, the primary difference being the manner in which the necessary high temperatures are obtained. These two types are as follows:

6.1.1.1 *Induction Type,* which depends upon the high-frequency electrical induction method of heating. This assembly shall be capable of attaining a temperature of at least 1482°C (2700°F) in the sample combustion zone, under the conditions set forth in Section 10 and shall be equipped with an additional induction coil located above the combustion zone, substantially as shown in Fig. 1.

6.1.1.2 The furnace work coil should have a minimum output of 500 W; the minimum input rating of the furnace must be 1000 W. With the correct amount of iron chips, weighed to ±0.05 g, the maximum plate current will be between 350 and 450 mA.

NOTE 1: **Warning** — This type of furnace is capable of inflicting high-frequency burns and high-voltage shocks. In addition to other precautions, maintain all guards properly. **Precaution** — Disconnect the furnace from the power line whenever electrical repairs or adjustments are made.

6.1.1.3 *Resistance Type,* capable of maintaining a temperature of at least 1371°C (2500°F).

6.1.2 *Absorber,* as described in Test Method D 1266.

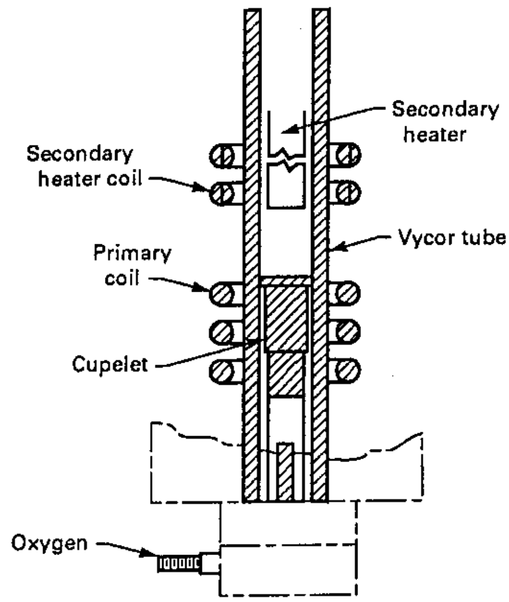


FIG. 1 COMBUSTION TUBE

NOTE 2 — Also suitable for use with either type of furnace is an automatic titrator, specifically designed for iodometry. This combines the functions of absorption and titration to a predetermined end point.

6.1.3 *Buret,* standard 25-mL or automatic types available from the manufacturers of the specific combustion units, are suitable (Note 2).

6.2 *Combustion and IR Detection System,* comprised of automatic balance, oxygen flow controls, drying tubes, combustion furnace, infrared detector and microprocessor. The furnace shall be capable of maintaining a nominal operating temperature of 1350°C (2460°F).

6.3 *Miscellaneous Apparatus* — Specific combustion assemblies require additional equipment such as crucibles, combustion boats, crucible lids, boat pushers, separator disks, combustion tubes, sample inserters, oxygen flow indicator, and oxygen drying trains. The additional equipment required is dependent on the type of furnace used and is available from the manufacturer of the specific combustion unit. To attain the lower sulfur concentration given in Section 1, the ceramics used with the induction furnace assembly shall be

ignited in a muffle furnace at 1371°C (2500°F) for at least 4 h before use.

6.4 *Sieve,* 60-mesh (250-mm).

7. Reagents and Materials

7.1 *Purity of Reagents* — Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

7.2 *Purity of Water* — Unless otherwise indicated, references to water shall be understood to mean reagent water as defined by Type II or III of Specification D 1193.

7.3 *Alundum* (Al_2O_3) or *Magnesium Oxide* (Com-Aid).

7.4 *Anhydrone (Magnesium Perchlorate).*

NOTE 3: **Precaution** — In addition to other precautions, handle magnesium perchlorate with care. Avoid contacting it with acid and organic materials. Reactions with fuel may be violent.

7.5 *Hydrochloric Acid* (3 + 197) — Dilute 30 mL of concentrated hydrochloric acid (HCl, relative density 1.19) to 2 L with water.

NOTE 4: **Warning** — Poison. Corrosive. May be fatal if swallowed. Liquid and vapor cause severe burns.

7.6 *Oxygen (Extra Dry)* — The oxygen shall be at least 99.5% pure and show no detectable sulfur by blank determination.

NOTE 5: **Warning** — Oxygen vigorously accelerates combustion.

7.7 *Phosphorus Pentoxide* (P_2O_5).

7.8 *Potassium Alum (Aluminum Potassium Sulfate).*

7.9 *Potassium Iodate, Standard Solution* (0.06238 *M,* 1 mL = 1 mg S) — Dissolve 2.225 g of potassium iodate (KIO_3) that has been dried at about 180°C to constant weight, in water and dilute to 1 L. Thoroughly mix the solution.

7.10 *Potassium Iodate, Standard Solution* (0.006238 *M,* 1 mL = 0.1 mg S) — Measure exactly 100 mL of KIO_3 solution (0.06238 *M,* 1 mL = 1 mg S) into a 1-L volumetric flask, and dilute to volume with water. Thoroughly mix the solution.

7.11 *Potassium Iodate, Standard Solution* (0.01248 *M,* 1 mL = 0.2 mg S) — Measure exactly 200 mL of KIO_3 solution (0.06238 *M,* 1 mL = 1 mg S) into a 1-L volumetric flask and dilute to volume with water. Thoroughly mix the solution.

7.12 *Ascarite,* 8 to 20 mesh.

7.13 *Special Materials for Induction-Type Furnaces:*

7.13.1 *Tin* (20 to 30-mesh).

7.13.2 *Iron-Chip Accelerator* having a sulfur content of not more than 0.005 mass %.

7.14 *Standard Sample* — Potassium alum [$AlK(SO_4)_2 \cdot 12H_2O$].

7.15 *Starch-Iodide Solution* — Make a paste by adding 9 g of soluble starch to 15 mL of water. Add this mixture, with stirring, to 500 mL of boiling water. Cool the mixture, add 15 g of potassium iodide (KI), and dilute to 1 L with water.

7.16 *Sulfuric Acid* (relative density 1.84) — Concentrated sulfuric acid (H_2SO_4).

NOTE 6: **Warning** — Poison. Corrosive. Strong oxidizer.

7.17 *Vanadium Pentoxide,* anhydrous, powdered V_2O_5.

8. Sampling

8.1 Take samples in accordance with the instructions in Practice D 4057.

9. Preparation of Apparatus

9.1 *Induction-Type Furnace* — Assemble the apparatus according to the instructions furnished by the manufacturer. Purify the oxygen by passing it through *(1)* H_2SO_4 (relative density 1.84), *(2)* Ascarite, and *(3)* magnesium perchlorate [$Mg(ClO_4)_2$] or phosphorus pentoxide (P_2O_5) (**Precaution** — see Note 3). Connect a rotameter between the purifying train and the furnace. Insert a small glass-wool plug in the upper end of the glass tubing connecting the furnace with the absorber to catch oxides of tin. Connect the exit end of the combustion tube to the absorber with glass tubing, using gum rubber tubing to make connections. Position the absorber so as to make this delivery line as short as

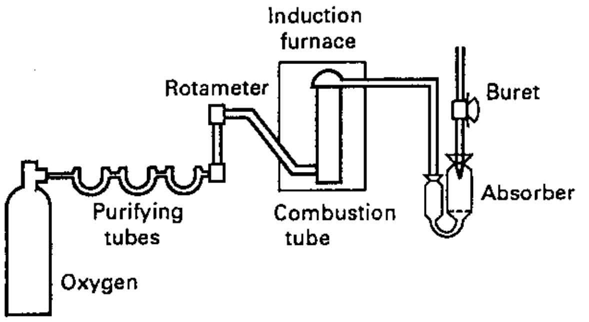


FIG. 2 SCHEMATIC ILLUSTRATION OF INDUCTION-TYPE FURNACE

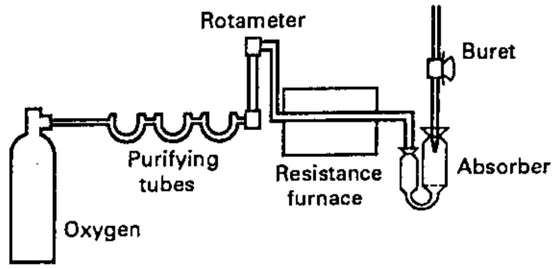


FIG. 3 SCHEMATIC ILLUSTRATION OF RESISTANCE-TYPE FURNACE

TABLE 1
SAMPLE WEIGHT FOR INDUCTION FURNACE

Sulfur Content, %	Weight of Sample to Be Taken, mg	Normality of Standard KIO_3 Solution for Titration
0 to 2	90[A]	0.006238
2 to 4	50 to 90	0.006238
4 to 10	50 to 90	0.01248
Over 10	12.1.1	(Note 7)

[A] Approximate.

TABLE 2
SAMPLE WEIGHT FOR RESISTANCE FURNACE

Sulfur Content, %	Weight of Sample to Be Taken, mg	Normality of Standard KIO_3 Solution for Titration
0 to 2	100 to 200	0.006238
2 to 5	100 to 200	0.01248
5 to 10	100 to 200	0.06238
Over 10	(Note 7)	(Note 7)

possible. Figure 2 illustrates schematically the assembled apparatus. Adjust the oxygen flow to 1 ± 0.05 L/min. Add 65 mL of HCl (3 + 197) and 2 mL of starch-iodide solution to the absorber. Add a sufficient amount of the appropriate standard KIO_3 solution (Table 1) to produce a faint blue color. This color will serve as the end point for the titration. Adjust the buret to zero. Turn on the furnace filament switch and allow at least 1 min warm-up before running samples (**Precaution** — see Note 3).

9.2 *Resistance-Type Furnace* — Assemble the apparatus according to the instructions furnished by the manufacturer. Purify the oxygen by passing it through *(1)* H_2SO_4 (relative density 1.84), *(2)* Ascarite, and *(3)* $Mg(ClO_4)_2$ or P_2O_5 (**Precaution** — see Note 3). Connect a rotameter between the purifying train and the furnace. Figure 3 illustrates schematically the assembled apparatus. Turn on the current and adjust the furnace control to maintain a constant temperature of 1316 ± 14°C (2400 ± 25°F). Adjust the oxygen flow rate to 2 ± 0.1 L/min. Add 65 mL of HCl (3 ± 197) and 2 mL of starch-iodide solution to the absorber. Add a few drops of the appropriate standard KIO_3 solution (Table 2) to produce a faint blue color. Adjust the buret to zero.

9.3 *Resistance-Type Furnace-IR Detection* — Assemble and adjust apparatus according to manufacturer's instructions. Initialize microprocessor, check power supplies, set oxygen pressure and flows and set furnace temperature to 1371°C (2500°F).

9.3.1 Condition a fresh anhydrone scrubber with four coal samples.

9.3.2 Calibrate the automatic balance according to manufacturer's instructions.

10. Standardization

10.1 *For Iodate Methods:*

10.1.1 *Determination of Alum Factor:*

10.1.1.1 Because these rapid combustion methods involve the reversible reaction $2SO_2 + O_2 = 2SO_3$, it is not possible to evolve all the sulfur as SO_2. The equilibrium of the reaction is temperature dependent and, in an oxygen atmosphere above 1316°C, about 97% of the sulfur is present as SO_2. To assure that the furnace is in proper adjustment and that its operation

produces acceptably high temperature, potassium alum is employed for standardizing the apparatus. Depending on the type of combustion equipment used, proceed as described in Sections 10 to 13 to determine the alum factor. Use 15 mg weighed to ±0.1 mg of potassium alum for this determination. Use the same materials in the determination of the alum and standardization factors as for the unknown samples. For example, V_2O_5 has a definite effect and should be included if used for unknowns as recommended in the procedure with the resistance-type furnace (Note 10).

10.1.1.2 Calculate the alum factor as follows:

$$\text{Alum factor } (AF) = (S_A \times W_A)/[100\ (V_a - V_b) \times C_1] \quad (1)$$

where:

S_A = mass percent sulfur in potassium alum used,
W_A = milligrams of potassium alum used,
V_a = millilitres of standard KIO_3 solution used in determining the alum factor,
V_b = millilitres of standard KIO_3 solution used in the blank determination, and
C_1 = sulfur equivalent of the standard KIO_3 solution used in determining the alum factor, mg/mL.

10.1.1.3 The alum factor should be in the range from 1.02 to 1.08. If values smaller than 1.02 are observed, confirm independently the sulfur content of the alum and the sulfur equivalent of the KIO_3 solution before repeating the alum factor determination. If values larger than 1.08 are observed, make adjustments in the equipment in accordance with the manufacturer's recommendation and repeat the alum factor determination.

10.1.2 *Determination of Standardization Factor:*

10.1.2.1 Because effects such as sample volatility can also affect the relative recovery as SO_2 of the sulfur originally present in the sample, it is necessary to determine a standardization factor. Proceed as described in Sections 10 to 13, using an oil sample of similar type to the unknown sample and of accurately known sulfur content.

10.1.2.2 For IR detection, determine and load the microprocessor with the calibration factor for the particular type of sample to be analyzed (lubricating oil, petroleum coke, residual fuel) as recommended by the manufacturer.

10.1.2.3 Calculate the standardization factor as follows:

$$\text{Standardization factor } (F_s) = (S_s \times W_s)/[100\ (V_s - V_b) \times C] \quad (2)$$

where:

S_s = mass percent sulfur in standardization sample used,
W_s = milligrams of standardization sample used,
V_b = millilitres of standard KIO_3 solution used in the blank determination,
V_s = millilitres of standard KIO_3 solution used in determining the standardization factor, and
C = sulfur equivalent of the standard KIO_3 solution used in determining the standardization factor, mg/mL.

10.1.3 *Quality Control* — Run a suitable analytical quality control sample several times daily. When the observed value lies between acceptable limits on a quality control chart, proceed with sample determinations.

11. Preparation of Coke

11.1 It is assumed that a representative sample has been received for analysis.

11.2 Grind and sieve the sample received so as to pass a 60-mesh (250-mm) sieve.

11.3 Dry the sieved material to constant weight at 105 to 110°C.

12. Procedure With Induction-Type Furnace

12.1 *Sample Preparation* — Add a 3.2 to 4.8-mm ($\frac{1}{8}$ to $\frac{3}{16}$-in.) layer of alundum or magnesium oxide to a sample crucible. Make a depression in the bed with the end of a stirring rod. Weigh the crucible to 0.1 mg. Weigh into the depression the proper amount of sample according to Table 1 (12.1.1) (Note 7). Cover the sample with a separator disk (Note 8. Place on the separator disk the predetermined amount of iron chips necessary to obtain the required temperature (6.1.1.2). This is usually between 1.2 and 2.0 g, but should be held constant with ±0.05 g. Sprinkle about 0.1 g of tin on the iron. Cover the crucible with a lid and place on the furnace pedestal.

12.1.1 Under no conditions shall an organic sample larger than 100 mg be burned in an induction-type furnace.

NOTE 7 — More concentrated KIO_3 solutions, such as the 0.06238 N solution, may be found more convenient for samples containing

more than 10% sulfur, The sample size and KIO_3 concentration should be chosen so that not more than 25 mL of titrant is needed.

NOTE 8 — The use of the separator disk is optional.

12.2 *Combustion and Titration* — Turn on the plate current switch. After about 1 min for warm-up, raise the pedestal and lock into position. The plate current will fluctuate for a few seconds and should gradually rise to a maximum value. Add the appropriate standard KIO_3 solution (Table 1) to the absorber to maintain the blue color. Should the absorber solution become completely colorless, discard the determination. Make KIO_3 additions as the rate of evolution of SO_2 diminishes such that, when combustion is completed, the intensity of the blue color is the same as the initial intensity. Combustion is complete when this color remains for at least 1 min and the plate current has dropped considerably. Record the volume of KIO_3 solution required to titrate the SO_2 evolved.

12.3 *Blank Determination* — Make a blank determination whenever a new supply of crucibles, materials, or reagents is used. Follow the preceding procedure, but omit the sample.

13. Procedure With Resistance-Type Furnace

13.1 *Sample Preparation* — Weigh into a combustion boat the proper amount of sample according to Table 2. Add 100 ± 5 mg of vanadium pentoxide and completely cover the mixture with Alundum.

13.2 *Combustion and Titration* — Place the boat in the cool portion of the combustion tube, near the entrance. To proceed with the combustion, push the boat containing the sample progressively into the hotter zone of the combustion tube using the equipment provided by the manufacturers. The boat should be advanced as rapidly as possible consistent with the rate of evolution of SO_2. Add the appropriate standard KIO_3 solution (Table 2) to the absorber to maintain the blue color. Should the absorber solution become completely colorless, discard the determination. Make KIO_3 additions as the rate of evolution of SO_2 diminishes such that, when combustion is completed, the intensity of the blue color is the same as the initial intensity. Combustion is complete when this color remains for at least 1 min. Record the volume of KIO_3 solution required to titrate the SO_2 evolved.

13.3 *Blank Determination* — Make a blank determination whenever a new supply of combustion boats, materials, or reagents is used. Follow the above procedure, but omit the sample.

14. Procedure With Resistance Furnace-IR Detection

14.1 Allow the system to warm up and the furnace to reach operating temperature.

14.2 After homogeneity of the sample is assured, select the sample size as follows: for liquid samples, take up to 0.13 g for analysis and for solid samples, take up to 0.4 g for analysis. In each case, mass percent sulfur times weight of sample must be less than or equal to four in the case of the SC32 instrument, and two in the case of the SC132 instrument. For other instruments, consult the manufacturer's instructions.

14.3 Determine and store the system blank value.

14.4 Weigh the samples into combustion boats and record the net weights. It is possible to weigh and store several weights in the microprocessor before beginning a series of burns.

14.4.1 Fill the combustion boat to one-third capacity with evenly spread MgO powder.

14.4.2 Form a slight trench in the MgO powder with a scoop.

14.4.3 Place the combustion boat on the balance and weigh an appropriate amount of the sample into the trench in the MgO powder. Enter the weight.

14.4.4 Remove the combustion boat from the balance and add MgO powder until the combustion boat is filled to two-thirds capacity.

NOTE 9 — If unacceptable repeatability is encountered for particular oil samples, combustion promoter such as V_2O_5 or the LECO product *Com-Aid* can be substituted for the MgO.

NOTE 10 — **Caution** — V_2O_5 can cause deterioration of the furnace ceramics so use it with care.

14.5 Initiate oxygen flow and load boat into furnace.

14.6 When the analysis is complete, read the result from the microprocessor.

14.7 Remove the expended combustion boat from the furnace.

14.8 Make repeated runs until two results differ by less than the repeatability of the method.

15. Calculation

15.1 *Calculation for Iodate Detection* — Calculate the sulfur content of the sample as follows:

$$\text{Sulfur, mass \%} = [100\ (V - V_b) \times F_s \times C]/W \quad (3)$$

where:

V = standard KIO_3 solution, mL, used in the analysis,

V_b = standard KIO_3 solution, mL, used in the blank determination,

F_s = standardization factor (see 10.1.2),

C = sulfur equivalent of the standard KIO_3 solution used in the analysis, mg/mL, and

W = milligrams of sample used in the analysis.

15.2 *Calculation for IR Detection:*

15.2.1 Report all results using the microprocessor.

15.2.2 Report the average of two results.

16. Report

16.1 In the range from 0.05 to 5.00 mass % sulfur, report to the nearest 0.01 mass %. In the range from 5 to 30 mass % sulfur, report to the nearest 0.1 mass %.

17. Precision and Bias

17.1 *For Petroleum Products by Iodate and IR Methods* — The precision of this test method as determined by statistical examination of interlaboratory results is as follows:

17.1.1 *Repeatability* — The difference between two test results obtained by the same operator with the same apparatus under constant operating conditions on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following values in only one case in twenty:

Sulfur, Mass, % Range	Repeatability Iodate	IR[8]
0.0 to 0.5	0.05	0.04
0.5 to 1.0	0.07	0.07
1.0 to 2.0	0.10	0.09
2.0 to 3.0	0.16	0.12
3.0 to 4.0	0.22	0.13
4.0 to 5.0	0.24	0.16

17.1.2 *Reproducibility* — The difference between two single and independent results obtained by different operators working in different laboratories on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following values in only one case in twenty:

Sulfur, Mass, % Range	Reproducibility Iodate	IR[8]
0.0 to 0.5	0.08	0.13
0.5 to 1.0	0.11	0.21
1.0 to 2.0	0.17	0.27
2.0 to 3.0	0.26	0.38
3.0 to 4.0	0.40	0.44
4.0 to 5.0	0.54	0.49

17.2 *For Petroleum Cokes by Iodate and IR Methods* — The precision of the test method as determined by statistical examination of interlaboratory results is as follows:

17.2.1 *Repeatability* — The difference between two test results obtained by the same operator with the same apparatus under constant operating conditions on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following values in only one case in twenty:

$$r = 0.05X$$

where X is the average of the two test results.

17.2.2 *Reproducibility* — The difference between two single and independent results obtained by different operators working in different laboratories on identical test material could, in the long run, in the normal and correct operation of the test method, exceed the following values in only one case in twenty:

$$R = 0.22X$$

where X is the average of the two test results.

17.3 *Bias* — The bias of the procedure in this test method is being determined.

18. Keywords

18.1 furnace; high temperature; induction furnace; iodate titration; IR detection; petroleum; resistance; sulfur; titration

STANDARD TEST METHOD FOR LIQUID PENETRANT EXAMINATION

SE-165

(Identical with ASTM Specification E 165-95)

1. Scope

1.1 This test method covers procedures for penetrant examination of materials. They are nondestructive testing methods for detecting discontinuities that are open to the surface such as cracks, seams, laps, cold shuts, laminations, through leaks, or lack of fusion and are applicable to in-process, final, and maintenance examination. They can be effectively used in the examination of nonporous, metallic materials, both ferrous and nonferrous, and of nonmetallic materials such as glazed or fully densified ceramics, certain nonporous plastics, and glass.

1.2 This test method also provides a reference:

1.2.1 By which a liquid penetrant examination process recommended or required by individual organizations can be reviewed to ascertain its applicability and completeness.

1.2.2 For use in the preparation of process specifications dealing with the liquid penetrant examination of materials and parts. Agreement by the user and the supplier regarding specific techniques is strongly recommended.

1.2.3 For use in the organization of the facilities and personnel concerned with the liquid penetrant examination.

1.3 This test method does not indicate or suggest criteria for evaluation of the indications obtained. It should be pointed out, however, that after indications have been produced, they must be interpreted or classified and then evaluated. For this purpose there must be a separate code or specification or a specific agreement to define the type, size, location, and direction of indications considered acceptable, and those considered unacceptable.

1.4 The values stated in inch-pound units are to be regarded as the standard. SI units are provided for information only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific hazard statements, see Notes 5, 12, and 20.

2. Referenced Documents

2.1 *ASTM Standards:*

- D 129 Test Method for Sulfur in Petroleum Products (General Bomb Method)
- D 516 Test Method for Sulfate Ion in Water
- D 808 Test Method for Chlorine in New and Used Petroleum Products (Bomb Method)
- D 1193 Specification for Reagent Water
- D 1552 Test Method for Sulfur in Petroleum Products (High-Temperature Method)
- D 4327 Test Method for Anions in Water in Chemically Suppressed Ion Chromatography
- E 433 Reference Photographs for Liquid Penetrant Inspection
- E 543 Practice for Evaluating Agencies that Perform Nondestructive Testing
- E 1208 Test Method for Fluorescent Liquid Penetrant Examination Using the Lipophilic Post-Emulsification Process
- E 1209 Test Method for Fluorescent Liquid Penetrant Examination Using the Water-Washable Process
- E 1210 Test Method for Fluorescent Liquid Penetrant Examination Using the Hydrophilic Post-Emulsification Process

E 1219 Test Method for Fluorescent Liquid Penetrant Examination Using the Solvent-Removable Process
E 1220 Test Method for Visible Penetrant Examination Using the Solvent-Removable Process
E 1316 Terminology for Nondestructive Examinations
E 1418 Test Method for Visible Penetrant Examination Using the Water-Washable Process

2.2 *ASNT Document:*
Recommended Practice SNT-TC-1A for Nondestructive Testing Personnel Qualification and Certification

2.3 *Military Standard:*
MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification

2.4 *APHA Standard:*
429 Method for the Examination of Water and Wastewater

3. Terminology

3.1 The definitions relating to liquid penetrant examination, which appear in Terminology E 1316, shall apply to the terms used in this standard.

4. Summary of Test Method

4.1 A liquid penetrant which may be a visible or a fluorescent material is applied evenly over the surface being examined and allowed to enter open discontinuities. After a suitable dwell time, the excess surface penetrant is removed. A developer is applied to draw the entrapped penetrant out of the discontinuity and stain the developer. The test surface is then examined to determine the presence or absence of indications.

NOTE 1: — The developer may be omitted by agreement between purchaser and supplier.

NOTE 2: **Caution** — Fluorescent penetrant examination shall not follow a visible penetrant examination unless the procedure has been qualified in accordance with 10.2, because visible dyes may cause deterioration or quenching of fluorescent dyes.

4.2 Processing parameters, such as surface precleaning, penetration time and excess penetrant removal methods, are determined by the specific materials used, the nature of the part under examination (that is, size, shape, surface condition, alloy), and type of discontinuities expected.

5. Significance and Use

5.1 Liquid penetrant examination methods indicate the presence, location and, to a limited extent, the nature and magnitude of the detected discontinuities.

TABLE 1
CLASSIFICATION OF PENETRANT EXAMINATION TYPES AND METHODS

Type I — Fluorescent Penetrant Examination
Method A — Water-washable (see Test Method E 1209)
Method B — Post-emulsifiable, lipophilic (see Test Method E 1208)
Method C — Solvent removable (see Test Method E 1219)
Method D — Post-emulsifiable, hydrophilic (see Test Method E 1210)
Type II — Visible Penetrant Examination
Method A — Water-washable (see Test Method E 1418)
Method C — Solvent removable (see Test Method E 1220)

Each of the various methods has been designed for specific uses such as critical service items, volume of parts, portability or localized areas of examination. The method selected will depend accordingly on the service requirements.

6. Classification of Penetrations and Methods

6.1 Liquid penetrant examination methods and types are classified as shown in Table 1.

6.2 *Fluorescent penetrant examination* utilizes penetrants that fluoresce brilliantly when excited by black light (see 8.9.1.2). The sensitivity of fluorescent penetrants depends on their ability to be retained in the various size discontinuities during processing, then to bleed out into the developer coating and produce indications that will fluoresce. Fluorescent indications are many times brighter than their surroundings when viewed under black light illumination.

6.3 *Visible penetrant examination* uses a penetrant that can be seen in visible light. The penetrant is usually red, so that the indications produce a definite contrast with the white background of the developer. The visible penetrant process does not require the use of black light. However, visible penetrant indications must be viewed under adequate white light (see 8.9.2.1).

7. Types of Materials

7.1 *Liquid penetrant examination materials* (see Notes 3, 4, and 5) consist of fluorescent and visible penetrants, emulsifiers (oil-base and water-base; fast and slow acting), solvent removers and developers. A family of liquid penetrant examination materials consists of the applicable penetrant and emulsifier or remover, as rec-

ommended by the manufacturer. Intermixing of materials from various manufacturers is not recommended.

NOTE 3: — Refer to 9.1 for special requirements for sulfur, halogen and alkali metal content.

NOTE 4: **Caution** — While approved penetrant materials will not adversely affect common metallic materials, some plastics or rubbers may be swollen or stained by certain penetrants.

NOTE 5: **Warning** — These materials may be flammable or emit hazardous and toxic vapors. Observe all manufacturer's instructions and precautionary statements.

7.2 *Penetrants:*

7.2.1 *Post-Emulsifiable Penetrants* are designed to be insoluble in water and cannot be removed with water rinsing alone. They are designed to be selectively removed from the surface using a separate emulsifier. The emulsifier, properly applied and given a proper emulsification time, combines with the excess surface penetrant to form a water-washable mixture, which can be rinsed from the surface, leaving the surface free of fluorescent background. Proper emulsification time must be experimentally established and maintained to ensure that over-emulsification does not occur, resulting in loss of indications.

7.2.2 *Water-Washable Penetrants* are designed to be directly water-washable from the surface of the test part, after a suitable penetrant dwell time. Because the emulsifier is "built-in" to the water-washable penetrant, it is extremely important to exercise proper process control in removal of excess surface penetrant to ensure against overwashing. Water-washable penetrants can be washed out of discontinuities if the rinsing step is too long or too vigorous. Some penetrants are less resistant to overwashing than others.

7.2.3 *Solvent-Removable Penetrants* are designed so that excess surface penetrant can be removed by wiping until most of the penetrant has been removed. The remaining traces should be removed with the solvent remover (see 8.6.4.1). To minimize removal of penetrant from discontinuities, care should be taken to avoid the use of excess solvent. Flushing the surface with solvent to remove the excess penetrant is prohibited.

7.3 *Emulsifiers:*

7.3.1 *Lipophilic Emulsifiers* are oil-miscible liquids used to emulsify the excess oily penetrant on the surface of the part, rendering it water-washable. The rate of diffusion establishes the emulsification time. They are either slow- or fast-acting, depending on their viscosity and chemical composition, and also the surface roughness of the area being examined (see 8.6.2).

7.3.2 *Hydrophilic Emulsifiers* are water-miscible liquids used to emulsify the excess oily fluorescent penetrant on the surface of the part, rendering it water-washable (see 8.6.3). These water-base emulsifiers (detergent-type removers) are supplied as concentrates to be diluted with water and used as a dip or spray. The concentration, use and maintenance shall be in accordance with manufacturer's recommendations.

7.3.2.1 Hydrophilic emulsifiers function by displacing the excess penetrant film from the surface of the part through detergent action. The force of the water spray or air/mechanical agitation in an open dip tank provides the scrubbing action while the detergent displaces the film of penetrant from the part surface. The emulsification time will vary, depending on its concentration, which can be monitored by the use of a suitable refractometer.

7.4 *Solvent Removers* function by dissolving the penetrant, making it possible to wipe the surface clean and free of excess penetrant as described in 8.6.4.

7.5 *Developers* — Development of penetrant indications is the process of bringing the penetrant out of open discontinuities through blotting action of the applied developer, thus increasing the visibility of the indications.

7.5.1 *Dry Powder Developers* are used as supplied (that is, free-flowing, non-caking powder) in accordance with 8.8.2. Care should be taken not to contaminate the developer with fluorescent penetrant, as the penetrant specks can appear as indications.

7.5.2 *Aqueous Developers* are normally supplied as dry powder particles to be either suspended or dissolved (soluble) in water. The concentration, use and maintenance shall be in accordance with manufacturer's recommendations (see 8.8.3).

NOTE 6: **Caution** — Aqueous developers may cause stripping of indications if not properly applied and controlled. The procedure should be qualified in accordance with 10.2.

7.5.3 *Nonaqueous Wet Developers* are supplied as suspensions of developer particles in a nonaqueous solvent carrier ready for use as supplied. Nonaqueous, wet developers form a coating on the surface of the part when dried, which serves as the developing medium (see 8.8.4).

NOTE 7: **Caution** — This type of developer is intended for application by spray only.

7.5.4 *Liquid Film Developers* are solutions or colloidal suspensions of resins/polymer in a suitable carrier. These developers will form a transparent or translucent coating on the surface of the part. Certain types of film developer may be stripped from the part and retained for record purposes (see 8.8.5).

8. Procedure

8.1 The following general processing guidelines apply (see Figs. 2, 3, and 4) to both fluorescent and visible penetrant examination methods (see Fig. 1).

8.2 *Temperature Limits* — The temperature of the penetrant materials and the surface of the part to be processed should be between 50 and 100°F (10 and 38°C). Where it is not practical to comply with these temperature limitations, qualify the procedure as described in 10.2 at the temperature of intended use and as agreed to by the contracting parties.

8.3 *Surface Conditioning Prior to Penetrant Examination* — Satisfactory results usually may be obtained on surfaces in the as-welded, as-rolled, as-cast, or as-forged conditions (or for ceramics in the densified conditions). Sensitive penetrants are generally less easily rinsed away and are therefore less suitable for rough surfaces. When only loose surface residuals are present, these may be removed by wiping with clean lint-free cloths. However, precleaning of metals to remove processing residuals such as oil, graphite, scale, insulating materials, coatings, and so forth, should be done using cleaning solvents, vapor degreasing or chemical removing processes. Surface conditioning by grinding, machining, polishing or etching shall follow shot, sand, grit or vapor blasting to remove the peened skin and when penetrant entrapment in surface irregularities might mask the indications of unacceptable discontinuities or otherwise interfere with the effectiveness of the examination. For metals, unless otherwise specified, etching shall be performed when evidence exists that previous cleaning, surface treatments or service usage have produced a surface condition that degrades the effectiveness of penetrant examination. (See Annex A1.1.1.8 for precautions.)

NOTE 8 — When agreed between purchaser and supplier, grit blasting without subsequent etching may be an acceptable cleaning method.

NOTE 9: **Caution** — Sand or shot blasting may possibly close discontinuities and extreme care should be used with grinding and machining operations to avoid masking discontinuities.

NOTE 10 — For structural or electronic ceramics, surface preparation by grinding, sand blasting and etching for penetrant examination is not recommended because of the potential for damage.

8.4 *Removal of Surface Contaminants:*

8.4.1 *Precleaning* — The success of any penetrant examination procedure is greatly dependent upon the surrounding surface and discontinuity being free of any contaminant (solid or liquid) that might interfere with the penetrant process. All parts or areas of parts to be examined must be clean and dry before the penetrant is applied. If only a section of a part, such as a weld, including the heat affected zone is to be examined, all contaminants shall be removed from the area being examined as defined by the contracting parties. "Clean" is intended to mean that the surface must be free of rust, scale, welding flux, weld spatter, grease, paint, oily films, dirt, and so forth, that might interfere with the penetrant process. All of these contaminants can prevent the penetrant from entering discontinuities (see Annex or Cleaning of Parts and Materials).

NOTE 11: **Caution** — Residues from cleaning processes such as strong alkalies, pickling solutions and chromates, in particular, may adversely react with the penetrant and reduce its sensitivity and performance.

8.4.2 *Drying after Cleaning* — It is essential that the surface of parts be thoroughly dry after cleaning, since any liquid residue will hinder the entrance of the penetrant. Drying may be accomplished by warming the parts in drying ovens, with infrared lamps, forced hot air, or exposure to ambient temperature.

8.5 *Penetrant Application* — After the part has been cleaned, dried, and is within the specified temperature range, the penetrant is applied to the surface to be examined so that the entire part or area under examination is completely covered with penetrant.

8.5.1 *Modes of Application* — There are various modes of effective application of penetrant such as dipping, brushing, flooding, or spraying. Small parts are quite often placed in suitable baskets and dipped into a tank of penetrant. On larger parts, and those with complex geometries, penetrant can be applied effectively by brushing or spraying. Both conventional and electrostatic spray guns are effective means of applying liquid penetrants to the part surfaces. Electrostatic spray application can eliminate excess liquid build-up of penetrant on the part, minimize overspray, and minimize the amount of penetrant entering hollow-cored passages which might serve as penetrant reservoirs, causing severe bleedout problems during examination. Aerosol sprays are conveniently portable and suitable for local application.

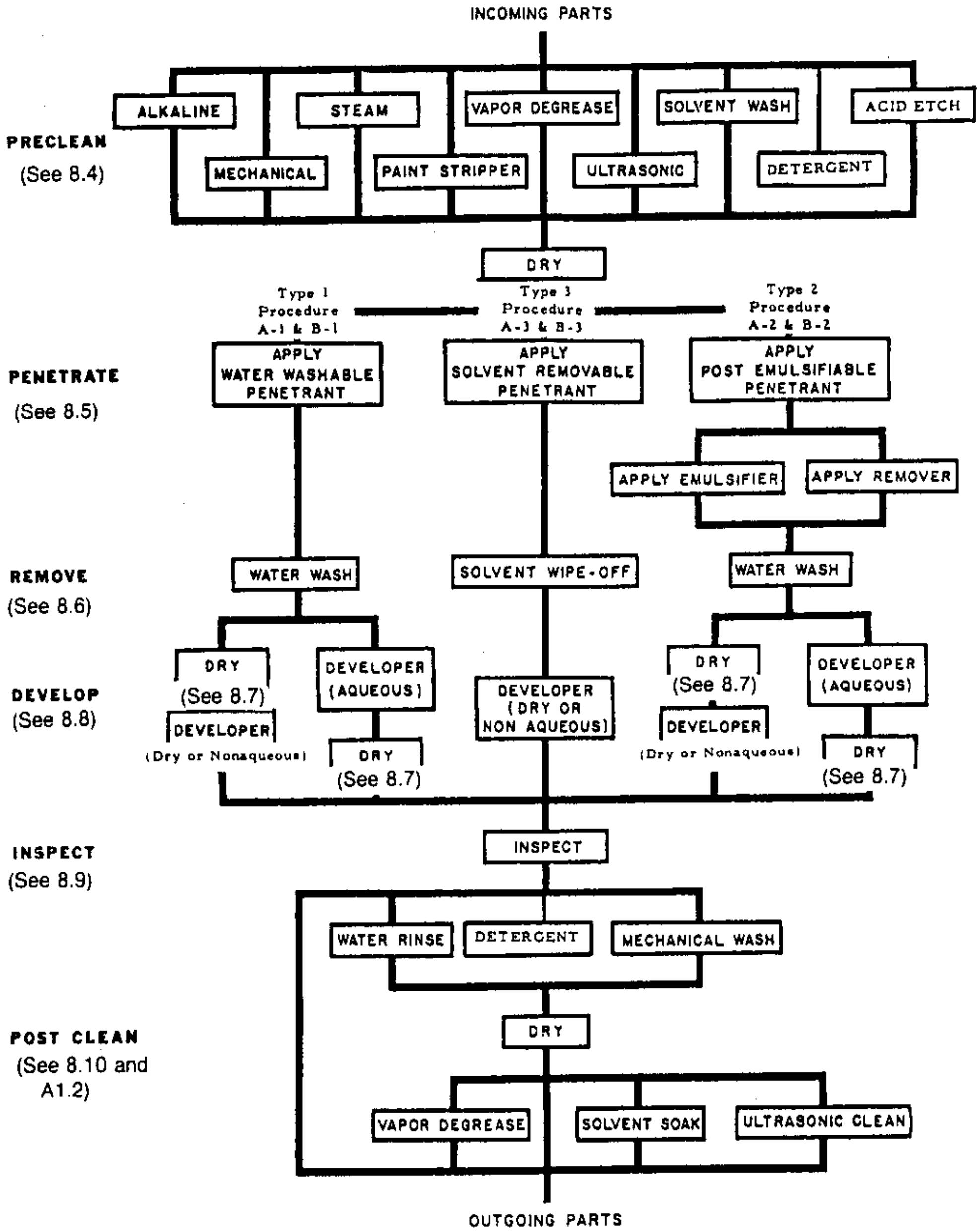


FIG. 1 FLUORESCENT AND VISIBLE PENETRANT INSPECTION GENERAL PROCESSING PROCEDURES FLOWSHEET

NOTE 12: **Caution** — Not all penetrant materials are suitable for electrostatic spray applications, so tests should be conducted prior to use.

NOTE 13: **Warning** — With spray applications, it is important that there be proper ventilation. This is generally accomplished through the use of a properly designed spray booth and exhaust system.

8.5.2 *Penetrant Dwell Time* — After application, allow excess penetrant to drain from the part (care should be taken to prevent pools of penetrant from forming on the part), while allowing for proper penetrant dwell time (see Table 2). The length of time the penetrant must remain on the part to allow proper penetration should be as recommended by the penetrant manufacturer. Table 2, however, provides a guide for selection of penetrant dwell times for a variety of materials, forms, and types of discontinuity. Unless

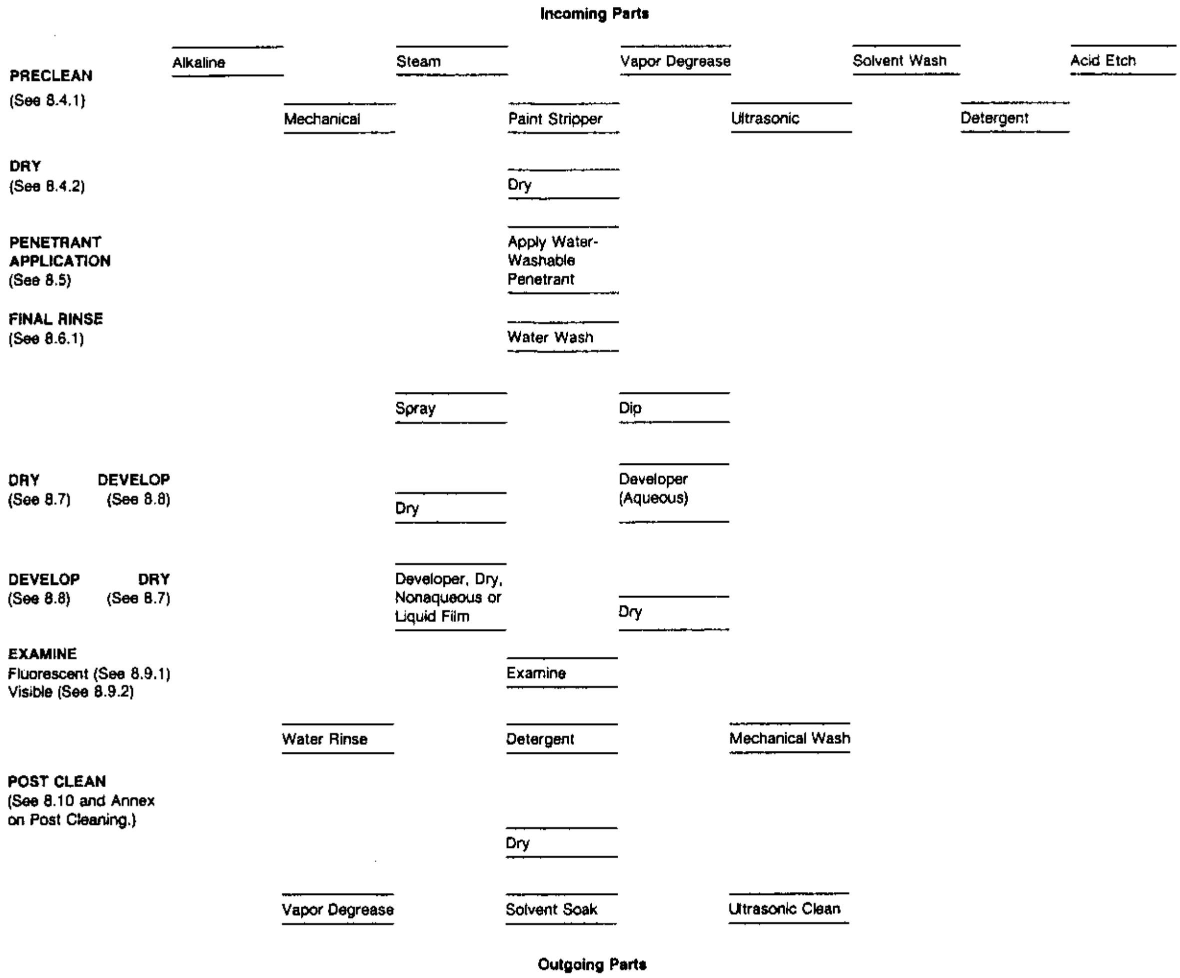


FIG. 2 GENERAL PROCEDURE FLOWSHEET FOR PENETRANT EXAMINATION USING THE WATER-WASHABLE PROCESS (TEST METHOD E 1209 FOR FLUORESCENT AND TEST METHOD E 1220 FOR VISIBLE LIGHT)

otherwise specified, the dwell time shall not exceed the maximum recommended by the manufacturer.

NOTE 14 — For some specific applications in structural ceramics (for example, detecting parting lines in slip-cast material), the required penetrant dwell time should be determined experimentally and may be longer than that shown in Table 1 and its notes.

8.6 *Penetrant Removal*

8.6.1 *Water Washable:*

8.6.1.1 *Removal of Excess Penetrants* — After the required penetration time, the excess penetrant on the surface being examined must be removed with water, usually a washing operation. It can be washed off manually, by the use of automatic or semi-automatic water-spray equipment or by immersion. For immersion rinsing, parts are completely immersed in the water bath with air or mechanical agitation. Accumulation of water in pockets or recesses of the surface must be avoided. If the final rinse step is not effective, as evidenced by excessive residual surface penetrant after rinsing, dry (see 8.7) and reclean the part, then reapply the penetrant for the prescribed dwell time.

(a) The temperature of the water should be relatively constant and should be maintained within the range of 50 to 100°F (10 to 38°C).

(b) Spray-rinse water pressure should not be greater than 40 psi (280 kPa).

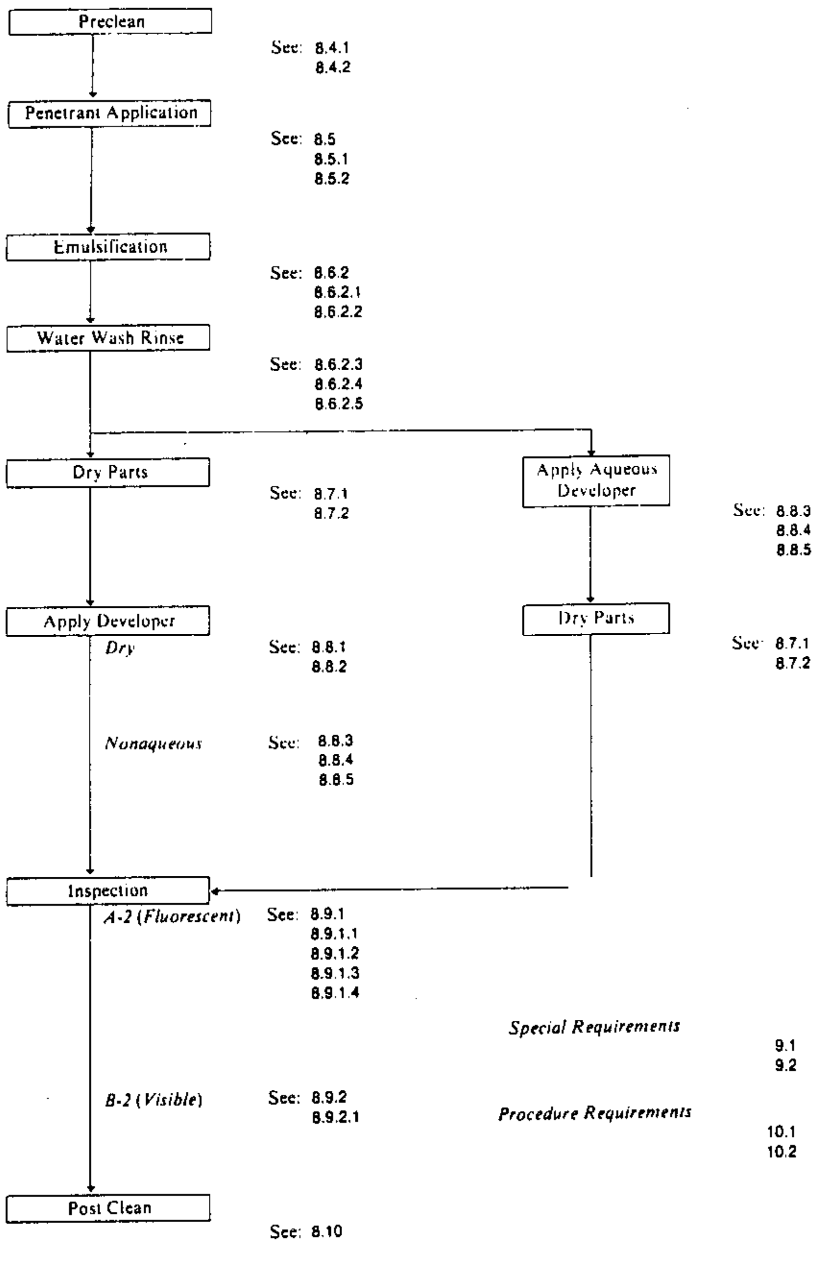


FIG. 3 TYPE 2 — POST EMULSIFIABLE PROCEDURES A-2 (FLUORESCENT) AND B-2 (VISIBLE)

(c) Rinse time should not exceed 120 s unless otherwise specified by part of material specification.

NOTE 15: **Caution** — Avoid overwashing. Excessive washing can cause penetrant to be washed out of discontinuities. With fluorescent penetrant methods perform the rinsing operation under black light so that it can be determined when the surface penetrant has been adequately removed.

8.6.1.2 *Removal by Wiping* — In special applications, penetrant removal may be performed by wiping the surface with a clean, absorbent material dampened with water until the excess surface penetrant is removed, as determined by examination under black light for fluorescent methods and white light for visible methods.

8.6.2 *Lipophilic Emulsification:*

8.6.2.1 *Application of Emulsifier* — After the required penetration time, the excess penetrant on the part must be emulsified by immersing or flooding

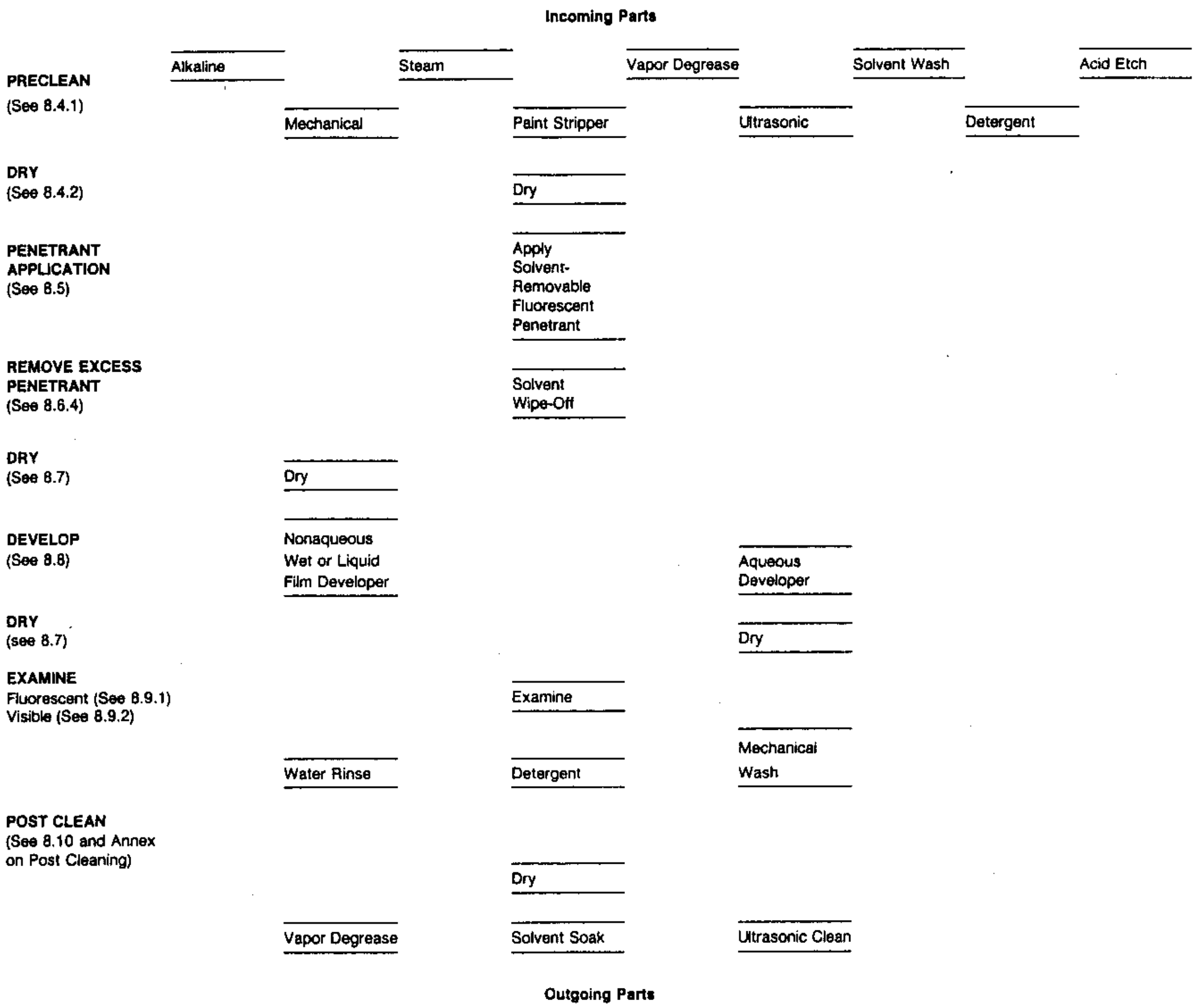


FIG. 4 SOLVENT-REMOVABLE PENETRANT EXAMINATION GENERAL PROCEDURE FLOWSHEET (TEST METHOD E 1219 FOR FLUORESCENT AND TEST METHOD E 1220 FOR VISIBLE LIGHT)

the parts with the required emulsifier (the emulsifier combines with the excess surface penetrant and makes the mixture removable with water rinsing). After application of the emulsifier, the parts are drained in a manner that prevents the emulsifier from pooling on the part(s).

8.6.2.2 *Emulsification Dwell Time* begins as soon as the emulsifier has been applied. The length of time that the emulsifier is allowed to remain on a part and in contact with the penetrant is dependent on the type of emulsifier employed and the surface condition (smooth or rough). Nominal emulsification time should be as recommended by the manufacturer. The actual emulsification time must be determined experimentally for each specific application. The surface finish (roughness) of the part is a significant factor in the selection of and in the emulsification time of an emulsifier. Contact time should be kept to the least possible time consistent with an acceptable background and should not exceed the maximum time specified for the part or material.

8.6.2.3 *Post Rinsing* — Effective post rinsing of the emulsified penetrant from the surface can be

TABLE 2
RECOMMENDED MINIMUM DWELL TIMES

Material	Form	Type of Discontinuity	Dwell Times[A] (minutes)	
			Penetrant[B]	Developer[C]
Aluminum, magnesium, steel, brass and bronze, titanium and high-temperature alloys	castings and welds	cold shuts, porosity, lack of fusion, cracks (all forms)	5	10
	wrought materials — extrusions, forgings, plate	laps, cracks (all forms)	10	10
Carbide-tipped tools		lack of fusion, porosity, cracks	5	10
Plastic	all forms	cracks	5	10
Glass	all forms	cracks	5	10
Ceramic	all forms	cracks, porosity	5	10

[A] For temperature range from 50 to 100°F (10 to 38°C) for fluorescent penetrants and 50 to 125°F (10 to 52°C) for visible penetrant.
[B] Maximum penetrant dwell time in accordance with 8.5.2.
[C] Development time begins as soon as wet developer coating has dried on surface of parts (recommended minimum). Maximum development time in accordance with 8.8.6.

accomplished using either manual, semi-automated, or automated water immersion or spray equipment or combinations thereof.

8.6.2.4 *Immersion* — For immersion post rinsing, parts are completely immersed in the water bath with air or mechanical agitation. The time and temperature should be kept constant.

(a) The maximum dip-rinse time should not exceed 120 s unless otherwise specified by part or material specification.

(b) The temperature of the water should be relatively constant and should be maintained within the range of 50 to 100°F (10 to 38°C). **Caution:** A touch-up rinse may be necessary after immersion.

8.6.2.5 *Spray Post Rinsing* — Effective post rinsing following emulsification can also be accomplished by either manual or automatic water spray rinsing of the parts as follows:

(a) Control rinse water temperature within the range of 50 to 100°F (10 to 38°C).

(b) Spray rinse water pressure should be in accordance with manufacturers' recommendations.

(c) The maximum spray rinse time should not exceed 120 s unless otherwise specified by part or materials specification.

8.6.2.6 *Rinse Effectiveness* — If the emulsification and final rinse step is not effective, as evidenced by excessive residual surface penetrant after emulsification and rinsing, dry (see 8.7) and reclean the part and reapply the penetrant for the prescribed dwell time.

8.6.3 *Hydrophilic Emulsification:*

8.6.3.1 *Prerinsing* — Directly after the required penetration time, it is recommended that the parts be prerinsed with water prior to emulsification (8.6.3.3). This step allows for the removal of excess surface penetrant from the parts prior to emulsification so as to minimize the degree of penetrant contamination in the hydrophilic emulsifier bath, thereby extending its life. In addition, prerinsing of penetrated parts minimizes possible oily penetrant pollution in the final rinse step of this process. This is accomplished by collecting the prerinsings in a holding tank, separating the penetrant from water.

8.6.3.2 *Prerinsing Controls* — Effective prerinsing is accomplished by either manual or automated water spray rinsing of the parts as follows:

(a) Water should be free of contaminants that could clog spray nozzles or leave a residue on parts.

(b) Control water temperature within the range of 50 to 100°F (10 to 38°C).

(c) Spray rinse at a water pressure of 25 to 40 psi (175 to 275 kPa).

(d) Prerinse time should be the least possible time (nominally 60 s maximum) to provide a consistent residue of penetrant on parts. Wash time is to be as specified by the part or material specification.

(e) Remove water trapped in cavities using filtered shop air at a nominal pressure 25 psi (175 kPa) or a suction device to remove water from pooled areas.

8.6.3.3 *Application of Emulsifier* — After the required penetration time and following the prerinse,

the residual surface penetrant on part(s) must be emulsified by immersing the part(s) in a hydrophilic emulsifier bath (8.6.3.4) or by spraying the part(s) with the emulsifier (8.6.3.5) thereby rendering the remaining residual surface penetrant water-washable in the final rinse station (8.6.3.6).

8.6.3.4 *Immersion* — For immersion application, parts are completely immersed in the emulsifier bath. The hydrophilic emulsifier should be gently agitated throughout the contact cycle.

(a) Bath concentration should be as recommended by the manufacturer. Most hydrophilic emulsifiers are used within the range of 20 to 33% in water. Nominal use concentration for immersion applications is 20%.

(b) Bath temperatures should be maintained between 50 and 100°F (10 to 38°C).

(c) Immersion contact time should be kept to the minimum time consistent with an acceptable background and should not exceed 120 s or the maximum time stipulated by the part or material specification.

(d) Emulsifier drain time begins immediately after parts have been withdrawn from the emulsifier tank and continues until the parts are washed in the final rinse station (8.6.3.6). This drain time should be kept to a minimum to avoid over emulsification and should not exceed 90 s.

8.6.3.5 *Spray Application* — For spray application following the prerinse step, parts are emulsified by the spray application of an emulsifier. All part surfaces should be evenly and uniformly sprayed to effectively emulsify the residual penetrant on part surfaces to render it water-washable.

(a) The concentration of the emulsifier for spray application should be in accordance with the manufacturer's recommendations, but should not exceed 5%.

(b) Temperature to be maintained at 50 to 100°F (10 to 38°C).

(c) The spray pressure should be 25 psi (175 kPa) max for air and 40 psi (280 kPa) max for water.

(d) Contact time should be kept to the minimum consistent with an acceptable background and should not exceed 120 s or the maximum time stipulated by the part or material specification.

8.6.3.6 *Post-Rinsing of Hydrophilic Emulsified Parts* — Effective post-rinsing of emulsified penetrant from the surface can be accomplished using either manual, semi-automated, or automated water immersion or spray equipment or combinations thereof.

8.6.3.7 *Immersion Post-Rinsing* — Parts are to be completely immersed in the water bath with air or mechanical agitation.

(a) The temperature of the water should be relatively constant and should be maintained within the range of 50 to 100°F (10 to 38°C).

(b) The maximum dip rinse time should not exceed 120 s unless otherwise specified by part or material specification. **Caution:** A touch-up rinse may be necessary after immersion.

8.6.3.8 *Spray Post-Rinsing* — Following emulsification parts can be post-rinsed by water spray rinsing as follows:

(a) Control rinse water temperature within the range of 50 to 100°F (10 to 38°C).

(b) Spray rinse water pressure should be in accordance with manufacturer's instructions.

(c) The maximum spray rinse time should not exceed 120 s unless otherwise specified by part or materials specification.

8.6.3.9 If the emulsification and final rinse steps are not effective, as evidenced by excessive residual surface penetrant after emulsification and rinsing, dry (see 8.7) and reclean the part and reapply the penetrant for the prescribed dwell time.

8.6.4 *Solvent-Removable Penetrants:*

8.6.4.1 *Removal of Excess Penetrant* — After the required penetration time, the excess penetrant is removed insofar as possible, by using wipers of a dry, clean, lint-free material and repeating the operation until most traces of penetrant have been removed. Then using a lint-free material lightly moistened with solvent remover the remaining traces are gently wiped to avoid removing penetrant from discontinuities. Avoid the use of excess solvent. If the wiping step is not effective, as evidenced by difficulty in removing the excess penetrant, dry the part (see 8.7), and reapply the penetrant for the prescribed dwell time. Flushing the surface with solvent following the application of the penetrant and prior to developing is prohibited.

8.7 *Drying* — Drying the surface of the part(s) is necessary prior to applying dry or nonaqueous developers or following the application of the aqueous developer. Drying time will vary with the size, nature, and number of parts under examination.

8.7.1 *Drying Modes* — Parts can be dried by using a hot-air recirculating oven, a hot or cold air blast, or by exposure to ambient temperature, particularly when the excess surface penetrant was removed

with a solvent. Drying is best done in a thermostatically controlled recirculating hot-air dryer. Local heating or cooling is permitted provided the temperature of the part remains in the range of 50 to 100°F (10 to 38°C) for fluorescent methods and in the range of 50 to 125°F (10 to 52°C) for visible methods unless otherwise agreed by the contracting parties.

NOTE 16: **Caution** — Drying oven temperature should not exceed 160°F (71°C).

8.7.2 *Drying Time Limits* — Do not allow parts to remain in the drying oven any longer than is necessary to dry the surface. Times over 30 min in the dryer may impair the sensitivity of the examination.

8.8 *Developer Application:*

8.8.1 *Modes of Application* — There are various modes of effective application of the various types of developers such as dusting, immersing, flooding or spraying. The size, configuration, surface condition, number of parts to be processed, and so forth, will influence the choice of developer application.

8.8.2 *Dry Powder Developer* — Dry powder developers should be applied immediately after drying in such a manner as to ensure complete part coverage. Parts can be immersed in a container of dry developer or in a fluid bed of dry developer. They can also be dusted with the powder developer through a hand powder bulb or a conventional or electrostatic powder gun. It is common and effective to apply dry powder in an enclosed dust chamber, which creates an effective and controlled dust cloud. Other means suited to the size and geometry of the specimen may be used, provided the powder is dusted evenly over the entire surface being examined. Excess powder may be removed by shaking or tapping the part, or by blowing with low-pressure (5 to 10 psi) (34 to 70 kPa) dry, clean, compressed air.

NOTE 17: **Caution** — The air stream intensity should be established experimentally for each application.

8.8.3 *Aqueous Developers* — Aqueous developers should be applied to the part immediately after the excess penetrant has been removed and prior to drying. Aqueous developers should be prepared and maintained in accordance with the manufacturer's instructions and applied in such a manner as to ensure complete, even, part coverage. Caution should be exercised when using an aqueous developer with water-washable penetrants to avoid possible stripping of indications. Aqueous developers may be applied by spraying (see Note 17), flowing, or immersing the part. It is common to immerse the parts in a prepared developer bath. Immerse parts only long enough to coat all of the part surfaces with the developer (see Note 18). Then remove parts from the developer bath and allow to drain. Drain all excess developer from recesses and trapped sections to eliminate pooling of developer, which can obscure discontinuities. Dry the parts in accordance with 8.7. The dried developer coating appears as a translucent or white coating on the part.

NOTE 18: **Caution** — Atomized spraying is not recommended since a spotty film may result.

NOTE 19: **Caution** — If parts are left in the bath too long, indications may leach out.

8.8.4 *Nonaqueous Wet Developers* — After the excess penetrant has been removed and the surface has been dried, apply developer by spraying in such a manner as to ensure complete part coverage with a thin, even film of developer. These types of developer carrier evaporate very rapidly at normal room temperature and do not, therefore, require the use of a dryer (see Note 20). Dipping or flooding parts with nonaqueous developers is prohibited, since they may flush or dissolve the penetrant from within the discontinuities because of the solvent action of these types of developers.

NOTE 20: **Warning** — The vapors from the evaporating, volatile solvent developer carrier may be hazardous. Proper ventilation should be provided in all cases, but especially when the surface to be examined is inside a closed volume, such as a process drum or a small storage tank.

8.8.5 *Liquid Film Developers* — Apply by spraying as recommended by the manufacturer. Spray parts in such a manner as to ensure complete part coverage of the area being examined with a thin, even film of developer.

8.8.6 *Developing Time* — The length of time the developer is to remain on the part prior to examination should be not less than 10 min. Developing time begins immediately after the application of dry powder developer and as soon as the wet (aqueous and nonaqueous) developer coating is dry (that is, the solvent carrier has evaporated to dryness). The maximum permitted developing times are 2 h for aqueous developers and 1 h for nonaqueous developers.

8.9 *Examination* — Perform examination of parts after the applicable development time as specified in 8.8.6 to allow for bleedout of penetrant from discontinuities into the developer coating. It is good practice to observe the bleedout while applying the developer as an aid in interpreting and evaluating indications.

8.9.1 *Fluorescent Light Examination:*

8.9.1.1 *Visible Ambient Light Level* — Examine fluorescent penetrant indications under black light in a darkened area. Visible ambient light should not exceed 2 ft candles (20 Lx). The measurement should be made with a suitable photographic-type visible light meter on the surface being examined.

8.9.1.2 *Black Light Level Control* — Black light intensity, minimum of 1000 $\mu W/cm^2$, should be measured on the surface being examined, with a suitable black light meter. The black light wavelength shall be in the range of 320 to 380 nm. The intensity should be checked weekly to ensure the required output. Reflectors and filters should be checked daily for cleanliness and integrity. Cracked or broken ultraviolet (UV) filters should be replaced immediately. Defective bulbs, which radiate UV energy, must be replaced before further use. Since a drop in line voltage can cause decreased black light output with consequent inconsistent performance, a constant-voltage transformer should be used when there is evidence of voltage fluctuation.

Caution: Certain high-intensity black light may emit unacceptable amounts of visible light, which will cause fluorescent indications to disappear. Care should be taken to use only bulbs certified by the supplier to be suitable for such examination purposes.

NOTE 21 — The recommended minimum light intensity in 8.9.1.2 is intended for general usage. For critical examinations, higher intensity levels may be required.

8.9.1.3 *Black Light Warm-Up* — Allow the black light to warm up for a minimum of 10 min prior to its use or measurement of the intensity of the ultraviolet light emitted.

8.9.1.4 *Visual Adaptation* — The examiner should be in the darkened area for at least 1 min before examining parts. Longer times may be necessary under some circumstances.

NOTE 22: **Caution** — Photochromic lenses shall not be worn during examination.

8.9.2 *Visible Light Examination:*

8.9.2.1 *Visible Light Level* — Visible penetrant indications can be examined in either natural or artificial light. Adequate illumination is required to ensure no loss in the sensitivity of the examination. A minimum light intensity at the examination site of 100 fc (1000 Lx) is recommended.

8.9.3 *Housekeeping* — Keep the examination area free of interfering debris, including fluorescent objects. Practice good housekeeping at all times.

8.9.4 *Evaluation* — Unless otherwise agreed, it is normal practice to interpret and evaluate the discontinuity based on the size of the indication (see Referenced Photographs E 433).

8.10 *Post Cleaning* — Post cleaning is necessary in those cases where residual penetrant or developer could interfere with subsequent processing or with service requirements. It is particularly important where residual penetrant examination materials might combine with other factors in service to produce corrosion. A suitable technique, such as a simple water rinse, waterspray, machine wash, vapor degreasing, solvent soak, or ultrasonic cleaning may be employed (see Annex on Post Cleaning). It is recommended that if developer removal is necessary, it should be carried out as promptly as possible after examination so that it does not "fix" on the part.

NOTE 23: **Caution** — Developers should be removed prior to vapor degreasing. Vapor degreasing can bake the developer on parts.

9. Special Requirements

9.1 *Impurities:*

9.1.1 When using penetrant materials on austenitic stainless steels, titanium, nickel-base or other high-temperature alloys, the need to restrict impurities such as sulfur, halogens and alkali metals must be considered. These impurities may cause embrittlement or corrosion, particularly at elevated temperatures. Any such evaluation should also include consideration of the form in which the impurities are present. Some penetrant materials contain significant amounts of these impurities in the form of volatile organic solvents. These normally evaporate quickly and usually do not cause problems. Other materials may contain impurities which are not volatile and may react with the part, particularly in the presence of moisture or elevated temperatures.

9.1.2 Because volatile solvents leave the surface quickly without reaction under normal examination procedures, penetrant materials are normally subjected to an evaporation procedure to remove the solvents before the materials are analyzed for impurities. The residue from this procedure is then analyzed in accordance with Test Method D 129, Test Method D 1552, or Test Method D 129 decomposition followed by Test Method D 516, Method B (Turbidimetric Method) for sulfur. The residue may also be analyzed by Test

Method D 808 or Annex A2 on Methods for Measuring Total Chlorine Content in Combustible Liquid Penetrant Materials (for halogens other than fluorine) and Annex A3 on Method for Measuring Total Fluorine Content in Combustible Liquid Penetration Materials (for fluorine). An alternative procedure, Annex A4 on Determination of Anions by Ion Chromatography, provides a single instrumental technique for rapid sequential measurement of common anions such as chloride, fluoride, and sulfate. Alkali metals in the residue are determined by flame photometry or atomic absorption spectrophotometry.

NOTE 24: — Some current standards indicate that impurity levels of sulfur and halogens exceeding 1% of any one suspect element may be considered excessive. However, this high a level may be unacceptable for some applications, so the actual maximum acceptable impurity level must be decided between supplier and user on a case by case basis.

9.2 *Evaluated-Temperature Examination* — Where penetrant examination is performed on parts that must be maintained at elevated temperature during examination, special materials and processing techniques may be required. Such examination requires qualification in accordance with 10.2. Manufacturer's recommendations should be observed.

10. Qualification and Requalification

10.1 *Personal Qualification* — When required by user/supplier agreement, all examination personnel shall be qualified/certified in accordance with a written procedure conforming to the applicable edition of recommended Practice SNT-TC-1A or MIL-STD-410.

10.2 *Procedure Qualification* — Qualification of procedures using times or conditions differing from those specified or for new materials may be performed by any of several methods and should be agreed by the contracting parties. A test piece containing one or more discontinuities of the smallest relevant size is used. The test piece may contain real or simulated discontinuities, providing it displays the characteristics of the discontinuities encountered in product examination.

10.3 *Nondestructive Testing Agency Qualification* — If a nondestructive testing agency as described in Practice E 543 is used to perform the examination, the agency shall meet the requirements of Practice E 543.

10.4 *Requalification* may be required when a change or substitution is made in the type of penetrant materials or in the procedure (see 10.2).

11. Keywords

11.1 fluorescent liquid penetrant testing; hydrophilic emulsification; lipophilic emulsification; liquid penetrant testing; nondestructive testing; solvent removable; visible liquid penetrant testing; water-washable methods

ANNEXES
(Mandatory Information)

A1. Cleaning of Parts and Materials

A1.1 Choice of Cleaning Method

A1.1.1 The choice of a suitable cleaning method is based on such factors as: (*1*) type of contaminant to be removed since no one method removes all contaminants equally well; (2) effect of the cleaning method on the parts; (*3*) practicality of the cleaning method for the part (for example, a large part cannot be put into a small degreaser or ultrasonic cleaner); and (*4*) specific cleaning requirements of the purchaser. The following cleaning methods are recommended:

A1.1.1.1 *Detergent Cleaning* — Detergent cleaners are nonflammable water-soluble compounds containing specially selected surfactants for wetting, penetrating, emulsifying, and saponifying various types of soils, such as grease and oily films, cutting and machining fluids, and unpigmented drawing compounds, etc. Detergent cleaners may be alkaline, neutral, or acidic in nature, but must be noncorrosive to the item being inspected. The cleaning properties of detergent solutions facilitate complete removal of soils and contamination from the surface and void areas, thus preparing them to absorb the penetrant. Cleaning time should average 10 to 15 min at 170 to 200°F (77 to 93°C) with moderate agitation, using concentrations (generally 6 to 8 oz/gal or 45 to 60 kg/m^3) recommended by the manufacturer of the cleaning compound.

A1.1.1.2 *Solvent Cleaning* — There are a variety of solvent cleaners that can be effectively utilized to dissolve such soils as grease and oily films, waxes and sealants, paints, and in general, organic matter. These

solvents should be residue-free, especially when used as a hand-wipe solvent or as a dip-tank degreasing solvent. Solvent cleaners are not recommended for the removal of rust and scale, welding flux and spatter, and in general, inorganic soils. **Caution:** Some cleaning solvents are flammable and can be toxic. Observe all manufacturers' instructions and precautionary notes.

A1.1.1.3 *Vapor Degreasing* — Vapor degreasing is a preferred method of removing oil or grease-type soils from the surface of parts and from open discontinuities. It will not remove inorganic-type soils (dirt, corrosion, salts, etc.), and may not remove resinous soils (plastic coatings, varnish, paint, etc.). Because of the short contact time, degreasing may not completely clean out deep discontinuities and a subsequent solvent soak is recommended.

A1.1.1.4 *Alkaline Cleaning:*

(a) Alkaline cleaners are nonflammable water solutions containing specially selected detergents for wetting, penetrating, emulsifying, and saponifying various types of soils. Hot alkaline solutions are also used for rust removal and descaling to remove oxide scale which can mask surface discontinuities. Alkaline cleaner compounds must be used in accordance with the manufacturers' recommendations. **Caution:** Parts cleaned by the alkaline cleaning process must be rinsed completely free of cleaner and thoroughly dried by heat prior to the penetrant inspection process [part temperature at the time of penetrant application shall not exceed 125°F (52°C)].

(b) Steam cleaning is a modification of the hot-tank alkaline cleaning method, which can be used for preparation of large, unwieldy parts. It will remove inorganic soils and many organic soils from the surface of parts, but may not reach to the bottom of deep discontinuities, and a subsequent solvent soak is recommended.

A1.1.1.5 *Ultrasonic Cleaning* — This method adds ultrasonic agitation to solvent or detergent cleaning to improve cleaning efficiency and decrease cleaning time. It should be used with water and detergent if the soil to be removed is inorganic (rust, dirt, salts, corrosion products, etc.), and with organic solvent if the soil to be removed is organic (grease and oily films, etc.). After ultrasonic cleaning, parts should be heated to remove the cleaning fluid, then cooled to at least 125°F (52°C), before application of penetrant.

A1.1.1.6 *Paint Removal* — Paint films can be effectively removed by bond release solvent paint remover or disintegrating-type hot-tank alkaline paint strippers. In most cases, the paint film must be completely removed to expose the surface of the metal. Solvent-type paint removers can be of the high-viscosity thickened type for spray or brush application or can be of low viscosity two-layer type for dip-tank application. Both types of solvent paint removers are generally used at ambient temperatures, as received. Hot-tank alkaline strippers are water-soluble powder compounds generally used at 8 to 16 oz/gal (60 to 120 kg/m^3) of water at 180 to 200°F (82 to 93°C). After paint removal, the parts must be thoroughly rinsed to remove all contamination from the void openings and then thoroughly dried.

A1.1.1.7 *Mechanical Cleaning and Surface Conditioning* — Metal-removing processes such as filing, buffing, scraping, mechanical milling, drilling, reaming, grinding, liquid honing, sanding, lathe cutting, tumble or vibratory deburring, and abrasive blasting, including abrasives such as glass beads, sand, aluminum oxide, ligno-cellulose pellets, metallic shot, etc., are often used to remove such soils as carbon, rust and scale, and foundry adhering sands, as well as to deburr or produce a desired cosmetic effect on the part. *These processes may decrease the effectiveness of the penetrant examination by smearing or peening over metal surfaces and filling discontinuities open to the surface, especially for soft metals such as aluminum, titanium, magnesium, and beryllium alloy.*

A1.1.1.8 *Acid Etching* — Inhibited acid solutions (pickling solutions) are routinely used for descaling part surfaces. Descaling is necessary to remove oxide scale, which can mask surface discontinuities and prevent penetrant from entering. Acid solutions/etchants are also used routinely to remove smeared metal that peens over surface discontinuities. Such etchants should be used in accordance with the manufacturers' recommendations. **Caution:**

NOTE A1 — Etched parts and materials must be rinsed completely free of etchants, the surface neutralized and thoroughly dried by heat prior to application of penetrants. Acids and chromates can adversely affect the fluorescence of fluorescent materials.

NOTE A2 — Whenever there is a possibility of hydrogen embrittlement as a result of acid solution/etching, the part should be baked at a suitable temperature for an appropriate time to remove the hydrogen before further processing. After baking, the part shall be cooled to a temperature below 125°F (52°C) before applying penetrants.

A1.1.1.9 *Air Firing of Ceramics* — Heating of a ceramic part in a clean, oxidizing atmosphere is an effective way of removing moisture or light organic soil or both. The maximum temperature that will not

cause degradation of the properties of the ceramic should be used.

A1.2 Post Cleaning

A1.2.1 *Removal of Developer* — Dry powder developer can be effectively removed with an air blow-off (free of oil) or it can be removed with water rinsing. Wet developer coatings can be removed effectively by water rinsing or water rinsing with detergent either by hand or with a mechanical assist (scrub brushing, washing machine, etc.). The soluble developer coatings simply dissolve off of the part with a water rinse.

A1.2.2 Residual penetrant may be removed through solvent action. Vapor degreasing (10 min minimum), solvent soaking (15 min minimum), and ultrasonic solvent cleaning (3 min minimum) techniques are recommended. In some cases, it is desirable to vapor degrease, then follow with a solvent soak. The actual time required in the vapor degreaser and solvent soak will depend on the nature of the part and should be determined experimentally.

A2. Methods for Measuring Total Chlorine Content in Combustible Liquid Penetrant Materials

A2.1 Scope and Application

A2.1.1 These methods cover the determination of chlorine in combustible liquid penetrant materials, liquid or solid. Its range of applicability is 0.001 to 5% using either of the alternative titrimetric procedures. The procedures assume that bromine or iodine will not be present. If these elements are present, they will be detected and reported as chlorine. The full amount of these elements will not be reported. Chromate interferes with the procedures, causing low or nonexistent end points. The method is applicable only to materials that are totally combustible.

A2.2 Summary of Methods

A2.2.1 The sample is oxidized by combustion in a bomb containing oxygen under pressure (**Caution,** see A2.2.1.1). The chlorine compounds thus liberated are absorbed in a sodium carbonate solution and the amount of chloride present is determined titrimetrically either against silver nitrate with the end point detected potiometrically (Method A) or coulometrically with the end point detected by current flow increase (Method B).

A2.2.1.1 *Safety* — Strict adherence to all of the provisions prescribed hereinafter ensures against explosive rupture of the bomb, or a blow-out, provided the bomb is of proper design and construction and in good mechanical condition. It is desirable, however, that the bomb be enclosed in a shield of steel plate at least $\frac{1}{2}$ in. (12.7 mm) thick, or equivalent protection be provided against unforeseeable contingencies.

A2.3 Apparatus

A2.3.1 *Bomb,* having a capacity of not less than 300 mL, so constructed that it will not leak during the test, and that quantitative recovery of the liquids from the bomb may be readily achieved. The inner surface of the bomb may be made of stainless steel or any other material that will not be affected by the combustion process or products. Materials used in the bomb assembly, such as the head gasket and leadwire insulation, shall be resistant to heat and chemical action, and shall not undergo any reaction that will affect the chlorine content of the liquid in the bomb.

A2.3.2 *Sample Cup,* platinum, 24 mm in outside diameter at the bottom, 27 mm in outside diameter at the top, 12 mm in height outside and weighing 10 to 11 g, opaque fused silica, wide-form with an outside diameter of 29 mm at the top, a height of 19 mm, and a 5-mL capacity (Note 1), or nickel (Kawin capsule form), top diameter of 28 mm, 15 mm in height, and 5-mL capacity.

NOTE A2.1 — Fused silica crucibles are much more economical and longer-lasting than platinum. After each use, they should be scrubbed out with fine, wet emery cloth, heated to dull red heat over a burner, soaked in hot water for 1 h, then dried and stored in a desiccator before reuse.

A2.3.3 *Firing Wire,* platinum, approximately No. 26 B & S gage.

A2.3.4 *Ignition Circuit* (Note A2.2), capable of supplying sufficient current to ignite the nylon thread or cotton wicking without melting the wire.

NOTE A2.2: **Caution** — The switch in the ignition circuit shall be of a type that remains open, except when held in closed position by the operator.

A2.3.5 *Nylon Sewing Thread,* or *Cotton Wicking,* white.

A2.4 Purity of Reagents

A2.4.1 Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used provided it is first ascertained that the reagent is of sufficiently high purity

to permit its use without lessening the accuracy of the determination.

A2.4.2 Unless otherwise indicated, references to water shall be understood to mean referee grade reagent water conforming to Specification D 1193.

A2.5 Decomposition

A2.5.1 *Reagents and Materials:*

A2.5.1.1 *Oxygen,* free of combustible material and halogen compounds, available at a pressure of 40 atm (4.05 MPa).

A2.5.1.2 *Sodium Carbonate Solution (50 g Na_2CO_3/L)* — Dissolve 50 g of anhydrous Na_2CO_3 or 58.5 g of $Na_2CO_3 \cdot H_2O$) or 135 g of $Na_2CO_3 \cdot 10H_2O$ in water and dilute to 1 L.

A2.5.1.3 *White Oil,* refined.

A2.5.2 *Procedure:*

A2.5.2.1 *Preparation of Bomb and Sample* — Cut a piece of firing wire approximately 100 mm in length. Coil the middle section (about 20 mm) and attach the free ends to the terminals. Arrange the coil so that it will be above and to one side of the sample cup. Place 5 mL of Na_2CO_3 solution in the bomb (Note A2.3), place the cover on the bomb and vigorously shake for 15 s to distribute the solution over the inside of the bomb. Open the bomb, place the sample-filled sample cup in the terminal holder, and insert a short length of thread between the firing wire and sample. Use of a sample weight containing over 20 mg of chlorine may cause corrosion of the bomb. The sample weight should not exceed 0.4 g if the expected chlorine content is 2.5% or above. If the sample is solid, not more than 0.2 g should be used. Use 0.8 g of white oil with solid samples. If white oil will be used (Note A2.4), add it to the sample cup by means of a dropper at this time (**Caution,** see Notes A2.5 and A2.6).

NOTE A2.3 — After repeated use of the bomb for chlorine determination, a film may be noticed on the inner surface. This dullness should be removed by periodic polishing of the bomb. A satisfactory method for doing this is to rotate the bomb in a lathe at about 300 rpm and polish the inside surface with Grit No. 2/0 or equivalent paper coated with a light machine oil to prevent cutting, and then with a paste of grit-free chromic oxide and water. This procedure will remove all but very deep pits and put a high polish on the surface. Before using the bomb, it should be washed with soap and water to remove oil or paste left from the polishing operation. Bombs with porous or pitted surfaces should never be used because of the tendency to retain chlorine from sample to sample. **Caution:** Do not use more than 1 g total of sample and white oil or other chlorine-free combustible material.

NOTE A2.4 — If the sample is not readily miscible with white oil, some other nonvolatile, chlorine-free combustible diluent may be employed in place of white oil. However, the combined weight of sample and nonvolatile diluent shall not exceed 1 g. Some solid additives are relatively insoluble, but may be satisfactorily burned when covered with a layer of white oil.

TABLE A2.1
GAGE PRESSURES

Capacity of Bomb, mL	Gage Pressure, atm (MPa) min[A]	max
300 to 350	38 (3.85)	40 (4.05)
350 to 400	35 (3.55)	37 (3.75)
400 to 450	30 (3.04)	32 (3.24)
450 to 500	27 (2.74)	29 (2.94)

[A] The minimum pressures are specified to provide sufficient oxygen for complete combustion and the maximum pressures present a safety requirement.

NOTE A2.5 — The practice of running alternately samples high and low in chlorine content should be avoided whenever possible. It is difficult to rinse the last traces of chlorine from the walls of the bomb and the tendency for residual chlorine to carry over from sample to sample has been observed in a number of laboratories. When a sample high in chlorine has preceded one low in chlorine content, the test on the low-chlorine sample should be repeated and one or both of the low values thus obtained should be considered suspect if they do not agree within the limits of repeatability of this method.

A2.5.2.2 *Addition of Oxygen* — Place the sample cup in position and arrange the nylon thread, or wisp of cotton so that the end dips into the sample. Assemble the bomb and tighten the cover securely. Admit oxygen (**Caution,** Note A2.6) slowly (to avoid blowing the sample from the cup) until a pressure is reached as indicated in Table A2.1.

Note A2.6: **Caution** — Do not add oxygen or ignite the sample if the bomb has been jarred, dropped, or tilted.

A2.5.2.3 *Combustion* — Immerse the bomb in a cold-water bath. Connect the terminals to the open electrical circuit. Close the circuit to ignite the sample. Remove the bomb from the bath after immersion for at least ten minutes. Release the pressure at a slow, uniform rate such that the operation requires not less than 1 min. Open the bomb and examine the contents. If traces of unburned oil or sooty deposits are found, discard the determination, and thoroughly clean the bomb before again putting it in use (Note A2.3).

A2.6 Analysis, Method A, Potentiometric Titration Procedure

A2.6.1 *Apparatus:*

A2.6.1.1 *Silver Billet Electrode.*

A2.6.1.2 *Glass Electrode,* pH measurement type.

A2.6.1.3 *Buret,* 25-mL capacity, 0.05-mL graduations.

A2.6.1.4 *Millivolt Meter,* or expanded scale pH meter capable of measuring 0 to 220 mV.

Note A2.7 — An automatic titrator is highly recommended in place of items A2.6.1.3 through A2.6.1.4. Repeatability and sensitivity of the method are much enhanced by the automatic equipment while much tedious effort is avoided.

A2.6.2 *Reagents and Materials:*

A2.6.2.1 *Acetone,* chlorine-free.

A2.6.2.2 *Methanol,* chlorine-free.

A2.6.2.3 *Silver Nitrate Solution (0.0282 N)* — Dissolve 4.7910 ± 0.0005 g of silver nitrate ($AgNO_3$) in water and dilute to 1 L.

A2.6.2.4 *Sodium Chloride Solution (0.0282 N)* — Dry a few grams of sodium chloride (NaCl) for 2 h at 130 to 150°C, weigh out 1.6480 ± 0.0005 g of the dried NaCl, dissolve in water, and dilute to 1 L.

A2.6.2.5 *Sulfuric Acid (1 + 2)* — Mix 1 volume of concentrated sulfuric acid (H_2SO_4, sp. gr 1.84) with 2 volumes of water.

A2.6.3 *Collection of Chlorine Solution* — Remove the sample cup with clean forceps and place in a 400-mL beaker. Wash down the walls of the bomb shell with a fine stream of methanol from a wash bottle, and pour the washings into the beaker. Rinse any residue into the beaker. Next, rinse the bomb cover and terminals into the beaker. Finally, rinse both inside and outside of the sample crucible into the beaker. Washings should equal but not exceed 100 mL. Add methanol to make 100 mL.

A2.6.4 *Determination of Chlorine* — Add 5 mL of H_2SO_4 (1:2) to acidify the solution (solution should be acid to litmus and clear of white Na_2CO_3 precipitate). Add 100 mL of acetone. Place the electrodes in the solution, start the stirrer (if mechanical stirrer is to be used), and begin titration. If titration is manual, set the pH meter on the expanded millivolt scale and note the reading. Add exactly 0.1 mL of $AgNO_3$ solution from the buret. Allow a few seconds stirring; then record the new millivolt reading. Subtract the second reading from the first. Continue the titration, noting each amount of $AgNO_3$ solution and the amount of difference between the present reading and the last reading. Continue adding 0.1-mL increments, making readings and determining differences between readings until a maximum difference between readings is obtained. The total amount of $AgNO_3$ solution required to produce this maximum differential is the end point. Automatic titrators continuously stir the sample, add titrant, measure the potential difference, calculate the differential, and plot the differential on a chart. The maximum differential is taken at the end point.

NOTE A2.8 — For maximum sensitivity, 0.00282 *N* $AgNO_3$ solution may be used with the automatic titrator. This dilute reagent should not be used with large samples or where chlorine content may be over 0.1% since these tests will cause end points of 10 mL or higher. The large amount of water used in such titrations reduces the differential between readings, making the end point very difficult to detect. For chlorine contents over 1% in samples of 0.8 g or larger, 0.282 *N* $AgNO_3$ solution will be required to avoid exceeding the 10-mL water dilution limit.

A2.6.5 *Blank* — Make blank determinations with the amount of white oil used but omitting the sample. (Liquid samples normally require only 0.15 to 0.25 g of white oil while solids require 0.7 to 0.8 g.) Follow normal procedure, making two or three test runs to be sure the results are within the limits of repeatability for the test. Repeat this blank procedure whenever new batches of reagents or white oil are used. The purpose of the blank run is to measure the chlorine in the white oil, the reagents, and that introduced by contamination.

A2.6.6 *Standardization* — Silver nitrate solutions are not permanently stable, so the true activity should be checked when the solution is first made up and then periodically during the life of the solution. This is done by titration of a known NaCl solution as follows: Prepare a mixture of the amounts of the chemicals (Na_2CO_3 solution, H_2SO_4 solution, acetone, and methanol) specified for the test. Pipet in 5.0 mL of 0.0282-*N* NaCl solution and titrate to the end point. Prepare and titrate a similar mixture of all the chemicals except the NaCl solution, thus obtaining a reagent blank reading. Calculate the normality of the $AgNO_3$ solution as follows:

$$N_{AgNO_3} = \frac{5.0 \times N_{NaCl}}{V_A - V_B}$$

where:

N_{AgNO_3} = normality of the $AgNO_3$ solution,

N_{NaCl} = normality of the NaCl solution,

V_A = millilitres of $AgNO_3$ solution used for the titration including the NaCl solution, and

V_B = millilitres of $AgNO_3$ solution used for the titration of the reagents only.

A2.6.7 *Calculation* — Calculate the chlorine content of the sample as follows:

$$\text{Chlorine, weight \%} = \frac{(V_S - V_B) \times N \times 3.545}{W}$$

where:

V_S = millilitres of $AgNO_3$ solution used by the sample,
V_B = millilitres of $AgNO_3$ solution used by the blank,
N = normality of the $AgNO_3$ solution, and
W = grams of sample used.

A2.6.8 *Precision and Accuracy:*

A2.6.8.1 The following criteria should be used for judging the acceptability of results:

A2.6.8.1.1 *Repeatability* — Results by the same analyst should not be considered suspect unless they differ by more than 0.006% or 10.5% of the value determined, whichever is higher.

A2.6.8.1.2 *Reproducibility* — Results by different laboratories should not be considered suspect unless they differ by more than 0.013% or 21.3% of the value detected, whichever is higher.

A2.6.8.1.3 *Accuracy* — The average recovery of the method is 86% to 89% of the actual amount present.

A2.7 Analysis, Method B, Coulometric Titration

A2.7.1 *Apparatus:*

A2.7.1.1 *Coulometric Chloride Titrator.*

A2.7.1.2 *Beakers,* two, 100-mL, or glazed crucibles (preferably with $1\frac{1}{2}$ in.-outside diameter bottom).

A2.7.1.3 *Refrigerator.*

A2.7.2 *Reagents:*

A2.7.2.1 *Acetic Acid, Glacial.*

A2.7.2.2 *Dry Gelatin Mixture.*

A2.7.2.3 *Nitric Acid.*

A2.7.2.4 *Sodium Chloride Solution* — 100 meq C/1. Dry a quantity of NaCl for 2 h at 130 to 150°C. Weigh out 5.8440 ± 0.0005 g of dried NaCl in a closed container, dissolve in water, and dilute to 1 L.

A2.7.3 *Reagent Preparation:*

NOTE A2.9 — The normal reagent preparation process has been slightly changed, due to the interference from the 50 mL of water required to wash the bomb. This modified process eliminates the interference and does not alter the quality of the titration.

A2.7.3.1 *Gelatin Solution* — A typical preparation is: Add approximately 1 L or hot distilled or deionized water to the 6.2 g of dry gelatin mixture contained in one vial supplied by the equipment manufacturer. Gently heat with continuous mixing until the gelatin is completely dissolved.

A2.7.3.2 Divide into aliquots each sufficient for one day's analyses. (Thirty millilitres is enough for approximately eleven titrations.) Keep the remainder in a refrigerator, but do not freeze. The solution will keep for about 6 months in the refrigerator. When ready to use, immerse the day's aliquot in hot water to liquefy the gelatin.

A2.7.3.3 *Glacial Acetic Acid-Nitric Acid Solution* — A typical ratio is 12.5 to 1 (12.5 parts CH_3COOH to 1 part HNO_3).

A2.7.3.4 Mix enough gelatin solution and of acetic acid-nitric acid mixture for one titration. (A typical mixture is 2.5 mL of gelatin solution and 5.4 mL of acetic-nitric acid mixture.)

NOTE A2.10 — The solution may be premixed in a larger quantity for convenience, but may not be useable after 24 h.

A2.7.3.5 Run at least three blank values and take an average according to the operating manual of the titrator. Determine separate blanks for both 5 drops of mineral oil and 20 drops of mineral oil.

A2.7.4 *Titration:*

A2.7.4.1 Weigh to the nearest 0.1 g and record the weight of the 100-mL beaker.

A2.7.4.2 Remove the sample crucible from the cover assembly support ring using a clean forceps, and, using a wash bottle, rinse both the inside and the outside with water into the 100-mL beaker.

A2.7.4.3 Empty the bomb shell into the 100-mL beaker. Wash down the sides of the bomb shell with water, using a wash bottle.

A2.7.4.4 Remove the cover assembly from the cover assembly support, and, using the wash bottle, rinse the under side, the platinum wire, and the terminals

into the same 100-mL beaker. The total amount of washings should be 50 ± 1 g.

A2.7.4.5 Add specified amounts of gelatin mixture and acetic acid-nitric acid mixture, or gelatin mix-acetic acid-nitric acid mixture, if this was premixed, into the 100-mL beaker that contains the 50 g of washings including the decomposed sample.

A2.7.4.6 Titrate using a coulometric titrimeter, according to operating manual procedure.

A2.7.5 *Calculations* — Calculate the chloride ion concentration in the sample as follows:

$$\text{Chlorine, weight \%} = \frac{(P - B) \times M}{W}$$

where:

P = counter reading obtained with the sample,

B = average counter reading obtained with average of the three blank readings,

M = standardization constant. This is dependent on the instrument range setting in use and the reading obtained with a known amount of the 100 meq of Cl per litre of solution, and

W = weight of sample used, g.

A2.7.6 *Precision and Accuracy:*

A2.7.6.1 Duplicate results by the same operator can be expected to exhibit the following relative standard deviations:

Approximate % Chlorine	RSD, %
1.0 and above	0.10
0.1	2.5
0.003	5.9

A2.7.6.2 The method can be expected to report values that vary from the true value by the following amounts:

0.1% chlorine and above	±2%
0.001 to 0.01% chlorine	±9%.

A2.7.6.3 If bromine is present, 36.5% of the true amount will be reported. If iodine is present, 20.7% of the true amount will be reported. Fluorine will not be detected.

A3. Method for Measuring Total Fluorine Content in Combustible Liquid Penetrant Materials

A3.1 Scope and Application

A3.1.1 This method covers the determination of fluorine in combustible liquid penetrant materials, liquid or solid, that do not contain appreciable amounts of interfering elements, or have any insoluble residue after combustion. Its range of applicability is 1 to 200 000 ppm.

A3.1.2 The measure of the fluorine content employs the fluoride selective ion electrode.

A3.2 Summary of Method

A3.2.1 The sample is oxidized by combustion in a bomb containing oxygen under pressure (**Caution,** see A3.2.1.1). The fluorine compounds thus liberated are absorbed in a sodium citrate solution and the amount of fluorine present is determined potentiometrically through the use of a fluoride selective ion electrode.

A3.2.1.1 *Safety* — Strict adherence to all of the provisions prescribed hereinafter ensures against explosive rupture of the bomb, or a blow-out, provided the bomb is of proper design and construction and in good mechanical condition. It is desirable, however, that the bomb be enclosed in a shield of steel plate at least ½ in. (12.7 mm) thick, or equivalent protection be provided against unforeseeable contingencies.

A3.3 Interferences

A3.3.1 Silicon, calcium, aluminum, magnesium, and other metals forming precipitates with fluoride ion will interfere if they are present in sufficient concentration to exceed the solubility of their respective fluorides. Insoluble residue after combustion will entrain fluorine even if otherwise soluble.

A3.4 Apparatus

A3.4.1 *Bomb,* having a capacity of not less than 300 mL, so constructed that it will not leak during the test, and that quantitative recovery of the liquids from the bomb may be readily achieved. The inner surface of the bomb may be made of stainless steel or any other material that will not be affected by the combustion process or products. Materials used in the bomb assembly, such as the head gasket and leadwire insulation, shall be resistant to heat and chemical action, and shall not undergo any reaction that will affect the fluorine content of the liquid in the bomb.

A3.4.2 *Sample Cup,* nickel, 20 mm in outside diameter at the bottom, 28 mm in outside diameter at the top, and 16 mm in height; or platinum, 24 mm in outside diameter at the bottom, 27 mm in outside diameter at the top, 12 mm in height, and weighing 10 to 11 g.

A3.4.3 *Firing Wire,* platinum, approximately No. 26 B & S gage.

A3.4.4 *Ignition Circuit* (Note A3.1), capable of supplying sufficient current to ignite the nylon thread or cotton wicking without melting the wire.

NOTE A3.1 **Caution** — The switch in the ignition circuit shall be of a type that remains open, except when held in closed position by the operator.

A3.4.5 *Nylon Sewing Thread,* or *Cotton Wicking,* white.

A3.4.6 *Funnel,* polypropylene (Note A3.2).

A3.4.7 *Volumetric Flask,* polypropylene, 100-mL (Note A3.2).

A3.4.8 *Beaker,* polypropylene, 150-mL (Note A3.2).

A3.4.9 *Pipet,* 100-μL, Eppendorf-type (Note A3.2).

A3.4.10 *Magnetic Stirrer* and TFE-coated magnetic stirring bar.

A3.4.11 *Fluoride Specific Ion Electrode* and suitable reference electrode.

A3.4.12 *Millivolt Meter* capable of measuring to 0.1 mV.

NOTE A3.2 — Glassware should never be used to handle a fluoride solution as it will remove fluoride ions from solution or on subsequent use carry fluoride ion from a concentrated solution to one more dilute.

A3.5 Reagents

A3.5.1 *Purity of Reagents* — Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

A3.5.2 *Purity of Water* — Unless otherwise indicated, all references to water shall be understood to mean Type I reagent water conforming to Specification D 1193.

A3.5.3 *Fluoride Solution, Stock (2000 ppm)* — Dissolve 4.4200 ± 0.0005 g of predried (at 130 to 150°C for 1 h, then cooled in a desiccator) sodium fluoride in distilled water and dilute to 1 L.

A3.5.4 *Oxygen,* free of combustible material and halogen compounds, available at a pressure of 40 atm (4.05 MPa).

A3.5.5 *Sodium Citrate Solution* — Dissolve 27 g of sodium citrate dihydrate in water and dilute to 1 L.

A3.5.6 *Sodium Hydroxide Solution (5 N)* — Dissolve 200 g of sodium hydroxide (NaOH) pellets in water and dilute to 1 L; store in a polyethylene container.

A3.5.7 *Wash Solution (Modified TISAB, Total Ionic Strength Adjustment Buffer)* — To 300 mL of distilled water, add 32 mL of glacial acetic acid, 6.6 g of sodium citrate dihydrate, and 32.15 g of sodium chloride. Stir to dissolve and then adjust the pH to 5.3 using 5 *N* NaOH solution. Cool and dilute to 1 L.

A3.5.8 *White Oil,* refined.

A3.6 Decomposition Procedure

A3.6.1 *Preparation of Bomb and Sample* — Cut a piece of firing wire approximately 100 mm in length. Coil the middle section (about 20 mm) and attach the free ends to the terminals. Arrange the coil so that it will be above and to one side of the sample cup. Place 10 mL of sodium citrate solution in the bomb, place the cover on the bomb, and vigorously shake for 15 s to distribute the solution over the inside of the bomb. Open the bomb, place the sample-filled sample cup in the terminal holder, and insert a short length of thread between the firing wire and the sample. The sample weight used should not exceed 1 g. If the sample is a solid, add a few drops of white oil at this time to ensure ignition of the sample.

NOTE A3.3 — Use of sample weights containing over 20 mg of chlorine may cause corrosion of the bomb. To avoid this it is recommended that for samples containing over 2% chlorine, the sample weight be based on the following table:

Chlorine Content, %	Sample weight, g	White Oil weight, g
2 to 5	0.4	0.4
5 to 10	0.2	0.6
10 to 20	0.1	0.7
20 to 50	0.05	0.7

Caution: Do not use more than 1 g total of sample and white oil or other fluorine-free combustible material.

A3.6.2 *Addition of Oxygen* — Place the sample cup in position and arrange the nylon thread, or wisp of cotton so that the end dips into the sample. Assemble the bomb and tighten the cover securely. Admit oxygen

TABLE A3.1
GAGE PRESSURES

Capacity of Bomb, mL	Gage Pressure, atm (MPa) min[A]	max
300 to 350	38	40
350 to 400	35	37
400 to 450	30	32
450 to 500	27	29

[A] The minimum pressures are specified to provide sufficient oxygen for complete combustion and the maximum pressures present a safety requirement.

(**Caution,** Note A3.4) slowly (to avoid blowing the sample from the cup) until a pressure is reached as indicated in Table A3.1.

NOTE A3.4: **Caution** — Do not add oxygen or ignite the sample if the bomb has been jarred, dropped, or tilted.

A3.6.3 *Combustion* — Immerse the bomb in a cold-water bath. Connect the terminals to the open electrical circuit. Close the circuit to ignite the sample. Remove the bomb from the bath after immersion for at least 10 min. Release the pressure at a slow, uniform rate such that the operation requires not less than 1 min. Open the bomb and examine the contents. If traces of unburned oil or sooty deposits are found, discard the determination, and thoroughly clean the bomb before again putting it in use.

A3.6.4 *Collection of Fluorine Solution* — Remove the sample cup with clean forceps and rinse with wash solution into a 100-mL volumetric flask. Rinse the walls of the bomb shell with a fine stream of wash solution from a wash bottle, and add the washings to the flask. Next, rinse the bomb cover and terminals into the volumetric flask. Finally, add wash solution to bring the contents of the flask to the line.

A3.7 Procedure

A3.7.1 Ascertain the slope (millivolts per ten-fold change in concentration) of the electrode as described by the manufacturer.

A3.7.2 Obtain a blank solution by performing the procedure without a sample.

A3.7.3 Immerse the fluoride and reference electrodes in solutions and obtain the equilibrium reading to 0.1 mV. (The condition of the electrode determines the length of time necessary to reach equilibrium. This may be as little as 5 min or as much as 20 min.)

A3.7.4 Add 100 μL of stock fluoride solution and obtain the reading after the same length of time necessary for A3.7.3.

A3.8 Calculation

A3.8.1 Calculate the fluorine content of the sample as follows:

$$\text{Fluorine, ppm} = \frac{\left[\dfrac{2 \times 10^{-4}}{10^{\Delta E_1/S} - 1} - \dfrac{2 \times 10^{-4}}{10^{\Delta E_2/S} - 1}\right]}{W} \times 10^6$$

where:

ΔE_1 = millivolt change in sample solution on addition of 100 μL of stock fluoride solution,

ΔE_2 = millivolt change in blank solution on addition of 100 μL of the stock fluoride solution,

S = slope of fluoride electrode as determined in A3.7.1, and

W = grams of sample.

A3.9 Precision and Bias

A3.9.1 *Repeatability* — The results of two determinations by the same analyst should not be considered suspect unless they differ by more than 1.1 ppm (0.00011%) or 8.0% of the amount detected, whichever is greater.

A3.9.2 *Reproducibility* — The results of two determinations by different laboratories should not be considered suspect unless they differ by 6.7 ppm or 129.0% of the amount detected, whichever is greater.

A3.9.3 *Bias* — The average recovery of the method is 62 to 64% of the amount actually present although 83 to 85% recoveries can be expected with proper technique.

A4. Determination of Anions by Ion Chromatography With Conductivity Measurement

A4.1 Scope and Application

A4.1.1 This method is condensed from ASTM procedures and APHA Method 429 and optimized for the analysis of detrimental substances in organic based materials. It provides a single instrumental technique for rapid, sequential measurement of common anions such as bromide, chloride, fluoride, nitrate, nitrite, phosphate, and sulfate.

A4.2 Summary of Method

A4.2.1 The material must be put in the form of an aqueous solution before analysis can be attempted. The sample is oxidized by combustion in a bomb containing oxygen under pressure. The products liberated are absorbed in the eluant present in the bomb at the time of ignition. This solution is washed from the bomb, filtered, and diluted to a known volume.

A4.2.1.1 A filtered aliquot of sample is injected into a stream of carbonate-bicarbonate eluant and passed through a series of ion exchangers. The anions of interest are separated on the basis of their relative affinities for a low capacity, strongly basic anion exchanger (guard and separator column). The separated anions are directed onto a strongly acidic cation exchanger (suppressor column) where they are converted to their highly conductive acid form and the carbonate-bicarbonate eluant is converted to weakly conductive carbonic acid. The separated anions in their acid form are measured by conductivity. They are identified on the basis of retention time as compared to standards. Quantitation is by measurement of peak area or peak height. Blanks are prepared and analyzed in a similar fashion.

A4.2.2 *Interferences* — Any substance that has a retention time coinciding with that of any anion to be determined will interfere. For example, relatively high concentrations of low-molecular-weight organic acids interfere with the determination of chloride and fluoride. A high concentration of any one ion also interferes with the resolution of others. Sample dilution overcomes many interferences. To resolve uncertainties of identification or quantitation use the method of known additions. Spurious peaks may result from contaminants in reagent water, glassware, or sample processing apparatus. Because small sample volumes are used, scrupulously avoid contamination.

A4.2.3 *Minimum Detectable Concentration* — The minimum detectable concentration of an anion is a function of sample size and conductivity scale used. Generally, minimum detectable concentrations are in the range of 0.05 mg/L for F^- and 0.1 mg/L for Br^-, Cl^-, NO_3^-, NO_2^-, PO_4^{3-}, and SO_4^{2-} with a 100-μL sample loop and a 10-μmho full-scale setting on the conductivity detector. Similar values may be achieved by using a higher scale setting and an electronic integrator.

A4.3 Apparatus

A4.3.1 *Bomb,* having a capacity of not less than 300 mL, so constructed that it will not leak during the test, and that quantitative recovery of the liquids from the bomb may be readily achieved. The inner surface of the bomb may be made of stainless steel or any other material that will not be affected by the combustion process or products. Materials used in the bomb assembly, such as the head gasket and leadwire insulation, shall be resistant to heat and chemical action, and shall not undergo any reaction that will affect the chlorine content of the liquid in the bomb.

A4.3.2 *Sample Cup,* platinum, 24 mm in outside diameter at the bottom, 27 mm in outside diameter at the top, 12 mm in height outside, and weighing 10 to 11 g; opaque fused silica, wide-form with an outside diameter of 29 mm at the top, a height of 19 mm, and a 5-mL capacity (Note A4.1), or nickel (Kawin capsule form), top diameter of 28 mm, 15 mm in height, and 5-mL capacity.

NOTE A4.1 — Fused silica crucibles are much more economical and longer lasting than platinum. After each use, they should be scrubbed out with fine, wet emery cloth, heated to dull red heat over a burner, soaked in hot water for 1 h then dried and stored in a desiccator before reuse.

A4.3.3 *Firing Wire,* platinum, approximately No. 26 B and S gage.

A4.3.4 *Ignition Circuit* (Note A4.2), capable of supplying sufficient current to ignite the nylon thread or cotton wicking without melting the wire.

NOTE A4.2: **Caution** — The switch in the ignition circuit shall be of a type that remains open, except when held in closed position by the operator.

A4.3.5 *Nylon Sewing Thread,* or *Cotton Wicking,* white.

A4.3.6 *Ion Chromatograph,* including an injection valve, a sample loop, guard, separator, and suppressor columns, a temperature-compensated small-volume conductivity cell (6 μL or less), and a strip chart recorder capable of full-scale response of 2 s or less. An electronic peak integrator is optional. The ion chromatograph shall be capable of delivering 2 to 5 mL eluant/min at a pressure of 1400 to 6900 kPa.

A4.3.7 *Anion Separator Column,* with styrene divinyl-benzene-based low-capacity pellicular anion-exchange resin capable of resolving Br^-, Cl^-, F^-, NO_3^-, NO_2^-, PO_4^{3-}, and SO_4^{2-}; 4 × 250 mm.

A4.3.8 *Guard Column,* identical to separator column except 4 × 50 mm, to protect separator column from fouling by particulates or organics.

A4.3.9 *Suppressor Column,* high-capacity cation-exchange resin capable of converting eluant and separated anions to their acid forms.

A4.3.10 *Syringe,* minimum capacity of 2 mL and equipped with a male pressure fitting.

A4.4 Reagents

A4.4.1 *Purity of Reagents* — Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent has sufficiently high purity to permit its use without lessening the accuracy of the determination.

A4.4.2 *Deionized or Distilled Water,* free from interferences at the minimum detection limit of each constituent and filtered through a 0.2-μm membrane filter to avoid plugging columns.

A4.4.3 *Eluant Solution,* sodium bicarbonate-sodium carbonate, 0.003M $NaHCO_3$, 0.0024M Na_2CO_3: dissolve 1.008 g $NaHCO_3$ and 1.0176 g Na_2CO_3 in water and dilute to 4 L.

A4.4.4 *Regenerant Solution 1,* H_2SO_4, 1 N, use this regenerant when suppressor is not a continuously regenerated one.

A4.4.5 *Regenerant Solution 2,* H_2SO_4, 0.025 N, dilute 2.8 mL conc H_2SO_4 to 4 L or 100 mL regenerant solution 1 to 4 L. Use this regenerant with continuous regeneration fiber suppressor system.

A4.4.6 *Standard Anion Solutions,* 100 mg/L, prepare a series of standard anion solutions by weighing the indicated amount of salt, dried to a constant weight at 105°C, to 1000 mL. Store in plastic bottles in a refrigerator; these solutions are stable for at least one month.

Anion	Salt	Amount, g/L
Cl^-	NaCl	1.6485
F^-	NaF	2.2100
Br^-	NaBr	1.2876
NO_3^-	$NaNO_3$	1.3707
NO_2^-	$NaNO_2$	1.4998
PO_4^{3-}	KH_2PO_4	1.4330
SO_4^{2-}	K_2SO_4	1.8141

A4.4.7 *Combined Working Standard Solution, High Range* — Combine 10 mL of the Cl^-, F^-, NO_3^-, NO_2^-, and PO_4^{3-} standard anion solutions, 1 mL of the Br^-, and 100 mL of the SO_4^{2-} standard solutions, dilute to 1000 mL, and store in a plastic bottle protected from light; contains 10 mg/L each of Cl^-, F^-, NO_3^-, NO_2^-, and PO_4^{3-}, 1 mg Br^-/L, and 100 mg SO_4^{2-}/L. Prepare fresh daily.

A4.4.8 *Combined Working Standard Solution, Low Range* — Dilute 100 mL combined working standard solution, high range, to 1000 mL and store in a plastic bottle protected from light; contains 1.0 mg/L each Cl^-, F^-, NO_3^-, NO_2^-, and PO_4^{3-}, 0.1 mg Br^-/L, and 10 mg SO_4^{2-}/L. Prepare fresh daily.

A4.4.9 *Alternative Combined Working Standard Solutions* — Prepare appropriate combinations according to anion concentration to be determined. If NO_2^- and PO_4^{3-} are not included, the combined working standard is stable for one month.

A4.5 Decomposition Procedure

A4.5.1 *Preparation of Bomb and Sample* — Cut a piece of firing wire approximately 100 mm in length. Coil the middle section (about 20 mm) and attach the free ends to the terminals. Arrange the coil so that it will be above and to one side of the sample cup. Place 5 mL of $Na_2CO_3/NaHCO_3$ solution in the bomb, place the cover on the bomb, and vigorously shake for 15 s to distribute the solution over the inside of the bomb. Open the bomb, place the sample-filled sample cup in the terminal holder, and insert a short length of thread between the firing wire and the sample. The sample weight used should not exceed 1 g. If the sample is a solid, add a few drops of white oil at this time to ensure ignition of the sample.

NOTE A4.3 — Use of sample weights containing over 20 mg of chlorine may cause corrosion of the bomb. To avoid this it is recommended that for samples containing over 2% chlorine, the sample weight be based on the following:

Chlorine content, %	Sample weight, g	White Oil weight, g
2 to 5	0.4	0.4
5 to 10	0.2	0.6
10 to 20	0.1	0.7
20 to 50	0.05	0.7

CAUTION: Do not use more than 1 g total of sample and white oil or other fluorine-free combustible material.

A4.5.2 *Addition of Oxygen* — Place the sample cup in position and arrange the nylon thread, or wisp of cotton so that the end dips into the sample. Assemble the bomb and tighten the cover securely. Admit oxygen (**Caution,** Note A4.4) slowly (to avoid blowing the sample from the cup) until a pressure is reached as indicated in Table A4.1.

NOTE A4.4: **Caution** — Do not add oxygen or ignite the sample if the bomb has been jarred, dropped, or tilted.

TABLE A4.1
GAGE PRESSURES

Capacity of Bomb, mL	Gage Pressures, atm min[A]	Gage Pressures, atm max
300 to 350	38	40
350 to 400	35	37
400 to 450	30	32
450 to 500	27	29

[A] The minimum pressures are specified to provide sufficient oxygen for complete combustion and the maximum pressures present a safety requirement.

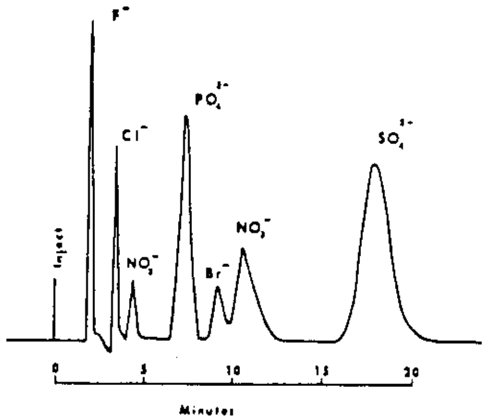


FIG. A4.1 TYPICAL ANION PROFILE

A4.5.3 *Combustion* — Immerse the bomb in a cold-water bath. Connect the terminals to the open electrical circuit. Close the circuit to ignite the sample. Remove the bomb from the bath after immersion for at least 10 min. Release the pressure at a slow, uniform rate such that the operation requires not less than 1 min. Open the bomb and examine the contents. If traces of unburned oil or sooty deposits are found, discard the determination, and thoroughly clean the bomb before again putting it in use.

A4.5.4 *Collection of Solution* — Remove the sample cup with clean forceps and rinse with deionized water and filter the washings into a 100-mL volumetric flask. Rinse the walls of the bomb shell with a fine stream of deionized water from a wash bottle, and add the washings through the filter paper to the flask. Next, rinse the bomb cover and terminals and add the washings through the filter into the volumetric flask. Finally, add deionized water to bring the contents of the flask to the line. Use aliquots of this solution for the ion chromatography (IC) analysis.

A4.6 Procedure

A4.6.1 *System Equilibration* — Turn on ion chromatograph and adjust eluant flow rate to approximate the separation achieved in Fig. A4.1 (2 to 3 mL/min). Adjust detector to desired setting (usually 10 μmho) and let system come to equilibrium (15 to 20 min). A stable base line indicates equilibrium conditions. Adjust detector offset to zero-out eluant conductivity; with the fiber suppressor adjust the regeneration flow rate to maintain stability, usually 2.5 to 3 mL/min.

A4.6.1.1 Set up the ion chromatograph in accordance with the manufacturer's instructions.

A4.6.2 *Calibration* — Inject standards containing a single anion or a mixture and determine approximate retention times. Observed times vary with conditions but if standard eluant and anion separator column are used, retention always in the order F^-, Cl^-, NO_2^-, PO_4^{3-}, Br^-, NO_3^-, and SO_4^{2-}. Inject at least three different concentrations for each anion to be measured and construct a calibration curve by plotting peak height or area against concentration on linear graph paper. Recalibrate whenever the detector setting is changed. With a system requiring suppressor regeneration, NO_2^- interaction with the suppressor may lead to erroneous NO_2^- results; make this determination only when the suppressor is at the same stage of exhaustion as during standardization or recalibrate frequently. In this type of system the water dip (see Note A4.4) may shift slightly during suppressor exhaustion and with a fast run column this may lead to slight interference for F^- or Cl^-. To eliminate this interference, analyze standards that bracket the expected result or eliminate the water dip by diluting the sample with eluant or by adding concentrated eluant to the sample to give the same HCO_3^-/CO_3^{2-} concentration as in the eluant. If sample adjustments are made, adjust standards and blanks identically.

NOTE A4.4 — Water dip occurs because water conductivity in sample is less than eluant conductivity (eluant is diluted by water).

A4.6.2.1 If linearity is established for a given detector setting, it is acceptable to calibrate with a single standard. Record the peak height or area and retention time to permit calculation of the calibration factor, F.

A4.6.3 *Sample Analysis* — Remove sample particulates, if necessary, by filtering through a prewashed 0.2-μm-porediam membrane filter. Using a prewashed

syringe of 1 to 10 mL capacity equipped with a male luer fitting inject sample or standard. Inject enough sample to flush sample loop several times: for 0.1 mL sample loop inject at least 1 mL. Switch ion chromatograph from load to inject mode and record peak heights and retention times on strip chart recorder. After the last peak (SO_4^{2-}) has appeared and the conductivity signal has returned to base line, another sample can be injected.

A4.6.4 *Regeneration* — For systems without fiber suppressor regenerate with 1 N H_2SO_4 in accordance with the manufacturer's instructions when the conductivity base line exceeds 300 μmho when the suppressor column is on line.

A4.7 Calculation

A4.7.1 Calculate concentration of each anion, in mg/L, by referring to the appropriate calibration curve. Alternatively, when the response is shown to be linear, use the following equation:

$$C = H \times F \times D$$

where:

C = mg anion/L,
H = peak height or area,
F = response factor – concentration of standard/height (or area) of standard, and
D = dilution factor for those samples requiring dilution.

TABLE A4.2
PRECISION AND ACCURACY OBSERVED FOR ANIONS AT VARIOUS CONCENTRATION LEVELS IN REAGENT WATER

Anion	Amount Added, mg/L	Amount Found, mg/L	Overall Precision, mg/L	Single-Operator Precision, mg/L	Significant Bias 95% Level
F^-	0.48	0.49	0.05	0.03	No
F^-	4.84	4.64	0.52	0.46	No
Cl	0.76	0.86	0.38	0.11	No
Cl^-	17	17.2	0.82	0.43	No
Cl	455	471	46	13	No
NO_2	0.45	0.09	0.09	0.04	Yes, neg
NO_2	21.8	19.4	1.9	1.3	Yes, neg
Br^-	0.25	0.25	0.04	0.02	No
Br^-	13.7	12.9	1.0	0.6	No
PO_4^{3-}	0.18	0.10	0.06	0.03	Yes, neg
PO_4^{3-}	0.49	0.34	0.15	0.17	Yes, neg
NO_3^-	0.50	0.33	0.16	0.03	No
NO_3^-	15.1	14.8	1.15	0.9	No
SO_4^{2-}	0.51	0.52	0.07	0.03	No
SO_4^{2-}	43.7	43.5	2.5	2.2	No

A4.8 Precision and Bias

A4.8.1 Samples of reagent water to which were added the common anions were analyzed in 15 laboratories with the results shown in Table A4.2.

STANDARD TEST METHOD FOR FLUORESCENT PENETRANT EXAMINATION USING THE WATER-WASHABLE PROCESS 01

SE-1209

(Identical with ASTM Specification E 1209-87)

DELETED

01

STANDARD TEST METHOD FOR FLUORESCENT PENETRANT EXAMINATION USING THE SOLVENT-REMOVABLE PROCESS

SE-1219

(Identical with ASTM Specification E 1219-87)

DELETED

STANDARD TEST METHOD FOR VISIBLE PENETRANT EXAMINATION USING THE SOLVENT-REMOVABLE PROCESS

01

SE-1220

(Identical with ASTM Specification E 1220-87)

DELETED

ARTICLE 25
MAGNETIC PARTICLE STANDARDS

STANDARD GUIDE FOR MAGNETIC PARTICLE EXAMINATION

SE-709

(Identical with ASTM Specification E 709-95)

1. Scope

1.1 This guide describes techniques for both dry and wet magnetic particle examination, a nondestructive method for detecting cracks and other discontinuities at or near the surface in ferromagnetic materials. Magnetic particle examination may be applied to raw material, semifinished material (billets, blooms, castings, and forgings), finished material and welds, regardless of heat treatment or lack thereof. It is useful for preventive maintenance examination.

1.1.1 This guide is intended as a reference to aid in the preparation of specifications/standards, procedures and techniques.

1.2 This guide is also a reference that may be used as follows:

1.2.1 To establish a means by which magnetic particle examination procedures recommended or required by individual organizations can be reviewed to evaluate their applicability and completeness.

1.2.2 To aid in the organization of the facilities and personnel concerned in magnetic particle examination.

1.2.3 To aid in the preparation of procedures dealing with the examination of materials and parts. This guide describes magnetic particle examination techniques that are recommended for a great variety of sizes and shapes of ferromagnetic materials and widely varying examination requirements. Since there are many acceptable differences in both procedure and technique, the explicit requirements should be covered by a written procedure (see Section 21).

1.3 This guide does not indicate, suggest, or specify acceptance standards for parts/pieces examined by these techniques. It should be pointed out, however, that after indications have been produced, they must be interpreted or classified and then evaluated. For this purpose there should be a separate code, specification, or a specific agreement to define the type, size, location, degree of alignment and spacing, area concentration, and orientation of indications that are unacceptable in a specific part versus those which need not be removed before part acceptance. Conditions where rework or repair are not permitted should be specified.

1.4 This guide describes the use of the following magnetic particle method techniques.

1.4.1 Dry magnetic powder (see 8.3),

1.4.2 Wet magnetic particle (see 8.4),

1.4.3 Magnetic slurry/paint magnetic particle (see 8.4.8), and

1.4.4 Polymer magnetic particle (see 8.4.8).

1.5 *Personnel Qualification* — Personnel performing examination to this guide shall be qualified and certified in accordance with ASNT Qualification and Certification of NDT Personnel, or SNT-TC-1A, or MIL-STD-410 for military purposes, or as specified in the contract or purchase order.

1.6 *Nondestructive Testing Agency* — If a nondestructive testing agency as described in Practice E 543 is used to perform the examination, the testing agency shall meet the requirements of Practice E 543.

1.7 Table of Contents:

1.8 The numerical values shown in inch-pound units are to be regarded as the standard. SI units are provided for information only.

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 93 Test Methods for Flash Point by Pensky-Martens Closed Tester

D 96 Test Methods for Water and Sediment in Crude Oil by Centrifuge Method (Field Procedure)

D 129 Test Method for Sulfur in Petroleum Products (General Bomb Method)

D 445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity)

D 808 Test Method for Chlorine in New and Used Petroleum Products (Bomb Method)

E 165 Test Method for Liquid Penetrant Examination

E 543 Practice for Evaluating Agencies that Perform Nondestructive Testing

E 1316 Terminology for Nondestructive Examinations

2.2 *Society of Automotive Engineers (SAE): Aerospace Materials Specifications:*
AMS 2641 Vehicle Magnetic Particle Inspection

2.3 *American Society for Nondestructive Testing:*
SNT-TC-1A Recommended Practice Magnetic Particle Method
ASNT Qualification and Certification of NDT Personnel

2.4 *U.S. Government Publications:*
FED-STD 313 Material Safety Data Sheets Preparation and the Submission of
MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification
MIL-STD-1949 Magnetic Particle Inspection, Method of

2.5 *OSHA Document:*
29CFR 1910.1200 Hazard Communication

3. Terminology

3.1 For definitions of terms used in the practice, refer to Terminology E 1316

4. Summary of Guide

4.1 *Principle* — The magnetic particle method is based on the principle that magnetic field lines when present in a ferromagnetic material, will be distorted by a change in material continuity, such as a sharp dimensional change or a discontinuity. If the discontinuity is open to or close to the surface of a magnetized material, flux lines will be distorted at the surface, a condition termed as "flux leakage." When fine magnetic particles are distributed over the area of the discontinuity while the flux leakage exists, they will be held in place and the accumulation of particles will be visible under the proper lighting conditions. While there are variations in the magnetic particle method, they all are dependent on this principle, that magnetic particles will be retained at the locations of magnetic flux leakage.

4.2 *Method* — While this practice permits and describes many variables in equipment, materials, and procedures, there are three steps essential to the method:

4.2.1 The part must be magnetized.

4.2.2 Magnetic particles of the type designated in the contract/purchase order/specification must be applied while the part is magnetized.

4.2.3 Any accumulation of magnetic particles must be observed, interpreted, and evaluated.

4.3 *Magnetization:*

4.3.1 *Ways to Magnetize* — A ferromagnetic material can be magnetized either by passing an electric current through the material or by placing the material within a magnetic field originated by an external source. The entire mass or a portion of the mass can be magnetized as dictated by size and equipment capacity or need. As previously noted, the discontinuity must interrupt the normal path of the magnetic field lines. If a discontinuity is open to the surface, the flux leakage will be at the maximum for that particular discontinuity. When that same discontinuity is below the surface, flux leakage evident on the surface will be less. Practically, discontinuities must be open to the surface, to create sufficient flux leakage to accumulate magnetic particles.

4.3.2 *Field Direction* — If a discontinuity is oriented parallel to the magnetic field lines, it may be essentially undetectable. Therefore, since discontinuities may occur in any orientation, it may be necessary to magnetize the part or area of interest twice or more sequentially in different directions by the same method or a combination of methods (see Section 13) to induce magnetic field lines in a suitable direction in order to perform an adequate examination.

4.3.3 *Field Strength* — The magnetic field must be of sufficient strength to indicate those discontinuities which are unacceptable, yet must not be so strong that an excess of particles is accumulated locally thereby masking relevant indications (see Section 14).

4.4 *Types of Magnetic Particles and Their Use* — There are various types of magnetic particles available for use in magnetic particle examination. They are available as dry powders (fluorescent and nonfluorescent) ready for use as supplied (see 8.3), powder concentrates (fluorescent and nonfluorescent) for dispersion in water or suspending light petroleum distillates (see 8.4), magnetic slurries/paints (see 8.4.7), and magnetic polymer dispersions (see 8.4.8).

4.5 *Evaluation of Indications* — When the material to be examined has been properly magnetized, the magnetic particles have been properly applied, and the excess particles properly removed, there will be accumulations of magnetic particles at the points of flux leakage. These accumulations show the distortion of the magnetic field and are called indications. Without disturbing the particles, the indications must be examined, classified, interpreted as to cause, compared with the acceptance standards, and a decision made concerning the disposition of the material that contains the indication.

4.6 *Typical Magnetic Particle Indications:*

4.6.1 *Surface Discontinuities* — Surface discontinuities, with few exceptions, produce sharp, distinct patterns (see Annex A).

4.6.2 *Near-Surface Discontinuities* — Near-surface discontinuities produce less distinct indications than those open to the surface. The patterns are broad, rather than sharp, and the particles are less tightly held (see Annex A).

5. Significance and Use

5.1 The magnetic particle method of nondestructive examination indicates the presence of surface and near-surface discontinuities in materials that can be magnetized (ferromagnetic). This method can be used for production examination of parts/components or structures and for field applications where portability of equipment and accessibility to the area to be examined are factors. The ability of the method to find small discontinuities can be enhanced by using fluorescent particles suspended in a suitable vehicle and by introducing a magnetic field of the proper strength whose orientation is as close as possible to 90° to the direction of the suspected discontinuity (see 4.3.2). Making the surface smoother improves mobility of the magnetic particles under the influence of the magnetic field to collect on the surface where magnetic flux leakage occurs.

6. Equipment

6.1 *Types* — There are a number of types of equipment available for magnetizing ferromagnetic parts and components. With the exception of a permanent magnet, all equipment requires a power source capable of delivering the required current levels to produce the magnetic field. The current used dictates the sizes of cables and the capability of relays, switching contacts, meters and rectifier if the power source is alternating current.

6.2 *Portability* — Portability, which includes the ability to hand carry the equipment, can be obtained from yokes. Their size limits their ability to provide the magnetic fields that can be obtained from equipment with larger current flows. General purpose mobile equipment which may be truck mounted is usually designed either for use with prods on the ends of two cables or with only the cables which are attached to the piece being examined, threaded through an opening in it or wrapped around it. Mobility is limited by the cable and size and the environment. Underwater examination on oil drilling platforms and oil production platforms offshore are examples of a hostile environment.

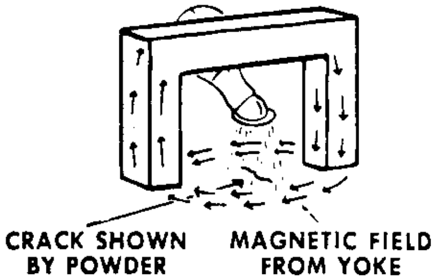
6.3 *Yokes* — Yokes are usually C-shaped electromagnets which induce a magnetic field between the poles (legs) and are used for local magnetization (Fig. 1). Many portable yokes have articulated legs (poles) that allow the legs to be adjusted to contact irregular surfaces or two surfaces that join at an angle.

6.3.1 *Permanent Magnets* — Permanent magnets are available but their use may be restricted for many applications. Permanent magnets can lose their magnetic field generating capacity by being partially demagnetized by a stronger flux field, being damaged, or dropped. In addition, the particle mobility, created by AC and half-wave rectified current pulsations in electromagnetic yokes, is not present. Particles, steel filings, chips, and scale clinging to the poles can create a housekeeping problem.

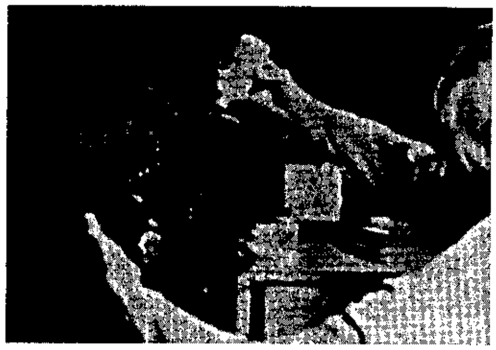
6.4 *Prods* — Prods are used for local magnetizations, see Fig. 2. The prod tips that contact the piece should be aluminum, copper braid, or copper pads rather than solid copper. With solid copper tips, accidental arcing during prod placement or removal can cause copper penetration into the surface which may result in metallurgical damage (softening, hardening, cracking, etc.). See 12.3.1.1(a). Open-circuit voltages should not exceed 25 V.

6.4.1 *Remote Control Switch* — A remote-control switch, which may be built into the prod handles, should be provided to permit the current to be turned on after the prods have been properly placed and to turn it off before the prods are removed in order to minimize arcing (arc burns). [See 12.3.1.1(a).]

6.5 *Black Light* — The black light must be capable of developing the required wavelengths of 330 to 390 nm with an intensity at the examination surface that satisfies 7.1.2. Wavelengths at or near 365 nm shall predominate. Suitable filters should remove the extraneous visible light emitted by black lights (violet or blue 405 and 435-nm Hg lines and greenish-yellow 577-nm Hg line). Some high-intensity black light bulbs may emit unacceptable amounts of greenish-yellow light which may cause fluorescent indications to become invisible. A drop, greater than 10%, in line voltage greater than ±10% can cause a change in black light output with consequent inconsistent performance. A



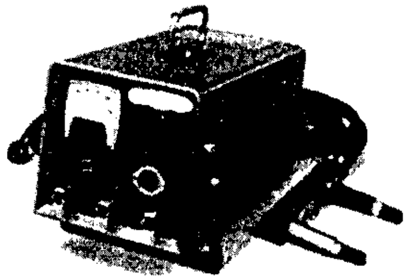
(a)



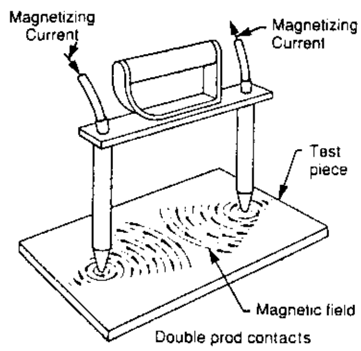
(b)

FIG. 1 YOKE METHOD OF PART MAGNETIZATION

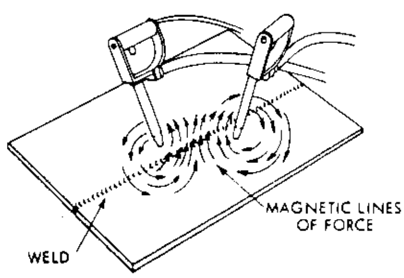
(a) Prod Magnetization



(b) Copper-Braided Tip Prods



(c) Single-Prod Contacts Magnetization



(d) Double-Prod Contacts

FIG. 2 LOCALIZED AREA MAGNETIZATION USING PROD TECHNIQUE

constant voltage transformer should be used where there is evidence of voltage changes greater than 10%.

6.6 *Equipment Verification* — See Section 20.

7. Examination Area

7.1 *Light Intensity for Examination* — Magnetic indications found using nonfluorescent particles are examined under visible light. Indications found using fluorescent particles must be examined under black (ultraviolet) light. This requires a darkened area with accompanying control of the visible light intensity.

7.1.1 *Visible Light Intensity* — The intensity of the visible light at the surface of the part/work piece undergoing examination should be a minimum of 100 foot candles (1000 lux). The intensity of ambient visible light in the darkened area where fluorescent magnetic particles examination is performed should not exceed 2 foot candles (20 lux).

7.1.1.1 *Field Inspections* — For some field inspections using nonfluorescent particles, visible light intensities as low as 50 foot candles (500 lux) may be used when agreed on by the contracting agency.

7.1.2 *Black (Ultraviolet) Light:*

7.1.2.1 *Black Light Intensity* — The black light intensity at the examination surface shall be not less than 1000 $\mu W/cm^2$ when measured with a suitable black light meter.

7.1.2.2 *Black Light Warm-up* — Allow the black light to warm up for a minimum of 5 min prior to its use or measurement of the intensity of the ultraviolet light emitted.

7.1.3 *Dark Area Eye Adaptation* — It is recommended that the inspector be in the darkened area for at least 3 min prior to examining parts using black light so that his eyes will adapt to dark viewing. **Caution** — Photochromic or permanently tinted lenses shall not be worn during examination.

7.2 *Housekeeping* — The examination area should be kept free of interfering debris. If fluorescent materials are involved, the area should also be kept free of fluorescent objects not related to the part/piece being examined.

8. Magnetic Particle Materials

8.1 *Particle Types* — The particles used in either dry or wet magnetic particle examination techniques are basically finely divided ferromagnetic materials which have been treated to impart color (fluorescent and nonfluorescent) in order to make them highly visible (contrasting) against the background of the surface being examined. The particles are designed for use either as a free flowing dry powder or for suspension at a given concentration in a suitable liquid medium.

8.2 *Particle Characteristics* — The magnetic particles must have high permeability to allow ease of magnetizing and attraction to the discontinuity and low retentivity so they will not be attracted (magnetic agglomeration) to each other. Control of particle size and shape is required to obtain consistent results. The particles should be nontoxic, free from rust, grease, paint, dirt, and other deleterious materials that might interfere with their use; see 20.5 and 20.6. Both dry and wet particles are considered safe when used in accordance with the manufacturer's instructions. They generally afford a very low hazard potential with regard to flammability and toxicity.

8.3 *Dry Particles* — Dry magnetic powders are designed to be used as supplied and are applied by spraying or dusting directly onto the surface of the part being examined. They are generally used on an expendable basis although the particles may be collected and reused. However, to maintain particle size and control possible contamination, this is not a normal practice. Dry powders may also be used under extreme environmental conditions. They are not affected by cold; therefore examination can be carried out at temperatures that would thicken or freeze wet baths. They are also heat resistant; some powders may be usable at temperatures up to 600°F (315°C). Some colored, organic coatings applied to dry particles to improve contrast lose their color at temperatures this high, making the contrast less effective. Fluorescent dry particles cannot be used at this high a temperature; the manufacturer should be contacted for the temperature limitation or tests should be run.

8.3.1 *Advantages* — The dry magnetic particle technique is generally superior to the wet technique for detection of near-surface discontinuities: (a) for large objects when using portable equipment for local magnetization; (b) superior particle mobility is obtained for relatively deep-seated flaws half-wave rectified current as the magnetizing source; (c) ease of removal.

8.3.2 *Disadvantages* — The dry magnetic particle technique; (a) cannot be used in confined areas without proper safety breathing apparatus; (b) Probability of Detection (POD) is appreciably less than the wet technique for fine surface discontinuities; (c) difficult to

use in overhead magnetizing positions; (d) no evidence exists of complete coverage of part surface as with the wet technique; (e) lower production rates can be expected with the dry technique versus the wet technique; and (f) it is difficult to adapt to any type of automotive system.

8.3.3 *Nonfluorescent Colors* — Although dry magnetic particle powder can be almost any color, the most frequently employed colors are light gray, black, red, or yellow. The choice is generally based on maximum contrast with the surface to be examined. The examination is done under visible light.

8.3.4 *Fluorescent* — Fluorescent dry magnetic particles are also available, but are not in general use primarily because of their higher cost and use limitations. They require a black light source and a darkened work area. These requirements are not often available in the field-type location where dry magnetic particle examinations are especially suitable.

8.4 *Wet Particle Systems* — Wet magnetic particles are designed to be suspended in a vehicle such as water or light petroleum distillate at a given concentration for application to the test surface by flowing, spraying, or pouring. They are available in both fluorescent and nonfluorescent concentrates. In some cases the particles are premixed with the suspending vehicle by the supplier, but usually the particles are supplied as a dry concentrate or paste concentrate which is mixed with the distillate or water by the user. The suspensions are normally used in wet horizontal magnetic particle equipment in which the suspension is retained in a reservoir and recirculated for continuous use. The suspension may also be used on an expendable basis dispensed from an aerosol.

8.4.1 *Primary Use* — Because the particles used are smaller, wet method techniques are generally used to locate smaller discontinuities than the dry method is used for. The liquid vehicles used will not perform satisfactorily when their viscosity exceeds 5cSt (5 mm^2/s) at the operating temperature. If the suspension vehicle is a hydrocarbon, its flash point limits the top temperature. Mixing equipment is usually required to keep wet method particles uniformly in suspension.

8.4.2 *Where Used* — The wet fluorescent method usually is performed indoors or in areas where shelter and ambient light level can be controlled and where proper application equipment is available.

8.4.3 *Color* — Fluorescent wet method particles glow a bright greenish-yellow when viewed under black light. Nonfluorescent particles are usually black or reddish brown, although other colors are available. The color often chosen for any given examination should be one that contrasts most with the test surface. Because contrast is invariably higher with fluorescent materials, these are utilized in most wet process examinations.

8.4.4 *Suspension Vehicles* — Generally the particles are suspended in a light petroleum (low-viscosity) distillate or conditioned water. (If sulfur or chlorine limits are specified, use Test Methods D 129 and D 808 to determine their values.

8.4.4.1 *Petroleum Distillates* — Low-viscosity light petroleum distillates vehicles (AMS 2641 Type 1 or equal) are ideal for suspending both fluorescent and nonfluorescent magnetic particles and are commonly employed.

(1) Advantages — Two significant advantages for the use of petroleum distillate vehicles are: (a) the magnetic particles are suspended and dispersed in petroleum distillate vehicles without the use of conditioning agents; and (b) the petroleum distillate vehicles provide a measure of corrosion protection to parts and the equipment used.

(2) Disadvantages — Principal disadvantages are flammability and availability. It is essential, therefore, to select and maintain readily available sources of supply of petroleum distillate vehicles that have as high a flash point as practicable to avoid possible flammability problems.

(3) Characteristics — Petroleum distillate vehicles to be used in wet magnetic particle examination should possess the following: (*a*) viscosity should not exceed 3.0 cSt (3 mm^2/s) at 100°F (38°C) and not more than 5.0 cSt (5 mm^2/s) at the lowest temperature at which the vehicle will be used; when tested in accordance with Test Method D 445, in order not to impede particle mobility (see 20.7.1), (*b*) minimum flash point, when tested in accordance with Test Methods D 93, should be 200°F (93°C) in order to minimize fire hazards (see 20.7.2), (*c*) odorless; not objectionable to user, (*d*) low inherent fluorescence if used with fluorescent particles; that is, it should not interfere significantly with the fluorescent particle indications (see 20.6.4.1), and (*e*) nonreactive; should not degrade suspended particles.

8.4.4.2 *Water Vehicles with Conditioning Agents* — Water may be used as a suspension vehicle for wet magnetic particles provided suitable conditioning agents are added which provide proper wet dispersing, in addition to corrosion protection for the parts being tested and the equipment in use. Plain water does not disperse some types of magnetic particles, does not

wet all surfaces, and is corrosive to parts and equipment. On the other hand, water suspensions of magnetic particles are safer to use since they are nonflammable. The selection and concentration of the conditioning agent should be as recommended by the particle manufacturer. The following are recommended properties for water vehicles containing conditioning agents for use with wet magnetic particle examination:

(1) Wetting Characteristics — The vehicle should have good wetting characteristics; that is, wet the surface to be tested, give even, complete coverage without evidence of dewetting the test surface. Smooth test surfaces require that a greater percentage of wetting agent be added than is required for rough surface. Nonionic wetting agents are recommended (see 20.7.3).

(2) Suspension Characteristics — Impart good dispersability; that is, thoroughly disperse the magnetic particles, without evidence of particle agglomeration.

(3) Foaming — Minimize foaming; that is, it should not produce excessive foam which would interfere with indication formation or cause particles to form scum with the foam.

(4) Corrosiveness — It should not corrode parts to be tested or the equipment in which it is used.

(5) Viscosity Limit — The viscosity of the conditioned water should not exceed a maximum viscosity of 3 cSt (3 mm^2/s) at 100°F (38°C) (see 20.7.1).

(6) Fluorescence — The conditioned water should not fluoresce if intended for use with fluorescent particles.

(7) Nonreactiveness — The conditioned water should not cause deterioration of the suspended magnetic particles.

(8) Water pH — The pH of the conditioned water should not be less than 6.0 or exceed 10.5.

(9) Odor — The conditioned water should be essentially odorless.

8.4.5 *Concentration of Wet Magnetic Particle Suspension* — The initial bath concentration of suspended magnetic particles should be as specified or as recommended by the manufacturer and should be checked by settling volume measurements and maintained at the specified concentration on a daily basis. If the concentration is not maintained properly, test results can vary greatly (see 20.6).

8.4.6 *Application of Wet Magnetic Particles* (see 15.2).

8.4.7 *Magnetic Slurry/Paint Systems* — Another type of examination vehicle is the magnetic slurry/paint type consisting of a heavy oil in which flakelike particles are suspended. The material is normally applied by brush before the part is magnetized. Because of the high viscosity, the material does not rapidly run off surfaces, facilitating the inspection of vertical or overhead surfaces. The vehicles may be combustible, but the fire hazard is very low. Other hazards are very similar to those of the oil and water vehicles previously described.

8.4.8 *Polymer-Based Systems* — The vehicle used in the magnetic polymer is basically a liquid polymer which disperses the magnetic particles and which cures to an elastic solid in a given period of time, forming fixed indications. Viscosity limits of standard wet technique vehicles do not apply. Care should be exercised in handling these polymer materials. Use in accordance with manufacturer's instructions and precautions. This technique is particularly applicable to examine areas of limited visual accessibility, such as bolt holes.

9. Part Preparation

9.1 *General* — The surface of the part to be examined should be essentially clean, dry, and free of contaminants such as dirt, oil, grease, loose rust, loose mill sand, loose mill scale, lint, thick paint, welding flux/slag, and weld splatter that might restrict particle movement. See 15.1.2 about applying dry particles to a damp/wet surface. When testing a local area, such as a weld, the areas adjacent to the surface to be examined, as agreed by the contracting parties, must also be cleaned to the extent necessary to permit detection of indications.

9.1.1 *Nonconductive Coatings* — Thin nonconductive coatings, such as paint in the order of 0.02 to 0.05 mm (1 or 2 mil) will not normally interfere with the formation of indications, but they must be removed at all points where electrical contact is to be made for direct magnetization. Indirect magnetization does not require electrical contact with the part/piece. See Section 12.2. If a nonconducting coating/plating is left on the area to be examined that has a thickness greater than 0.05 mm (2 mil), it must be demonstrated that discontinuities can be detected through the maximum thickness applied.

9.1.2 *Conductive Coatings* — A conductive coating (such as chrome plating and heavy mill scale on wrought products resulting from hot forming operations) can mask discontinuities. As with nonconductive coatings, it must be demonstrated that the discontinuities can be detected through the coating.

9.1.3 *Residual Magnetic Fields* — If the part/piece holds a residual magnetic field from a previous

magnetization that will interfere with the examination, the part must be demagnetized. See Section 18.

9.2 *Cleaning Examination Surface* — Cleaning of the test surface may be accomplished by detergents, organic solvents, or mechanical means. As-welded, as-rolled, as-cast, or as-forged surfaces are generally satisfactory, but if the surface is unusually nonuniform, as with burned-in sand or a very rough weld deposit, interpretation may be difficult because of mechanical entrapment of the magnetic particles. In case of doubt, any questionable area should be recleaned and reexamined (see 9.1). An extensive presentation of applicable cleaning methods is described in Annex A1 of Test Method E 165.

9.2.1 *Plugging and Masking Small Holes and Openings* — Unless prohibited by the purchaser, small openings and oil holes leading to obscure passages or cavities can be plugged or masked with a suitable nonabrasive material which is readily removed. In the case of engine parts, the material must be soluble in oil. Effective masking must be used to protect components that may be damaged by contact with the particles or particle suspension.

10. Sequence of Operations

10.1 *Sequencing Particle Application and Establishing Magnetic Flux Field* — The sequence of operation in magnetic particle examination applies to the relationship between the timing and application of particles and establishing the magnetizing flux field. Two basic techniques apply, that is, continuous (see 10.1.1 and 10.1.2) and residual (see 10.1.3), both of which are commonly employed in industry.

10.1.1 *Continuous Magnetization* — Continuous magnetization is employed for most applications utilizing either dry or wet particles and should be used unless specifically prohibited in the contract, purchase order, or specification. The sequence of operation for the dry and the wet continuous magnetization techniques are significantly different and are discussed separately in 10.1.1.1 and 10.1.1.2.

10.1.1.1 *Dry Continuous Magnetization Technique* — Unlike a wet suspension, dry particles lose most of their mobility when they contact the surface of a part. Therefore, it is imperative that the part/area of interest be under the influence of the applied magnetic field while the particles are still airborne and free to be attracted to leakage fields. This dictates that the flow of magnetizing current be initiated prior to the application of dry magnetic particles and terminated after the application of powder has been completed and any excess has been blown off. Magnetizing currents of the half-wave rectified alternating and unrectified AC provide additional particle mobility on the surface of the part. Examination with dry particles is usually carried out in conjunction with prod-type localized magnetizations, and buildup of indications is observed as the particles are being applied.

10.1.1.2 *Wet Continuous Magnetization Technique* — The wet continuous magnetization technique generally applies to those parts processed on a horizontal wet type unit. In practice, it involves bathing the part with the examination medium to provide an abundant source of suspended particles on the surface of the part and terminating the bath application immediately prior to cutting off of the magnetizing current. The duration of the magnetizing current is typically on the order of $\frac{1}{2}$ s with two or more shots given to the part.

10.1.1.3 *Polymer or Slurry Continuous Magnetization Technique* — Prolonged or repeated periods of magnetization are often necessary for polymer- or slurry-base suspensions because of slower inherent magnetic particle mobility in the high-viscosity suspension vehicles.

10.1.2 *True Continuous Magnetization Technique* — In this technique, the magnetizing current is sustained throughout both the processing and examination of the part.

10.1.3 *Residual Magnetization Techniques:*

10.1.3.1 *Residual Magnetization* — In this technique, the examination medium is applied after the magnetizing force has been discontinued. It can be used only if the material being tested has relatively high retentivity so the residual leakage field will be of sufficient strength to attract and hold the particles and produce indications. This technique may be advantageous for integration with production or handling requirements or for intentionally limiting the sensitivity of the examination. It has found wide use examining pipe and tubular goods. Unless demonstrations with typical parts indicate that the residual field has sufficient strength to produce relevant indications of discontinuities (see 20.8) when the field is in proper orientation, the continuous method should be used.

10.1.3.2 *Current Quick Break* — Equipment, full-wave rectified AC, for residual magnetization must be designed to provide a consistent quick break of the magnetizing current.

FIG. 3 COIL MAGNETIZATION

11. Types of Magnetizing Currents

11.1 *Basic Current Types* — The four basic types of current used in magnetic particle examination to establish part magnetization are alternating current, single phase half-wave rectified alternating current, full-wave rectified alternating current, and for a special application, DC.

11.1.1 *Alternating Current (AC)* — Part magnetization with alternating current is preferred for those applications where examination requirements call for the detection of discontinuities, such as fatigue cracks, that are open to the surface. Associated with AC is a "skin effect" that confines the magnetic field at or near to the surface of a part. In contrast, both half-wave rectified alternating current and full-wave rectified alternating current produce a magnetic field having maximum penetrating capabilities which should be used when near-surface discontinuities are of concern. Alternating current is also extensively used for the demagnetization of parts after examination. The through-coil technique is normally used for this purpose due to its simple, fast nature. See Fig. 3.

11.1.2 *Half-Wave Rectified Alternating Current* — Half-wave rectified alternating current is frequently used in conjunction with dry particles and localized magnetization (for example, prods or yokes) to achieve some depth of penetration for detection of typical discontinuities found in weldments and ferrous castings. As with AC for magnetization, single-phase current is utilized and average value measured as "magnetizing current."

11.1.3 *Full-Wave Rectified Alternating Current* — Full-wave rectified alternating current may utilize single- or three-phase current. Three-phase current has the advantage of lower line amperage whereas single-phase equipment is less expensive. Full-wave rectified AC is commonly used when the residual method is to be employed. With the continuous method, full-wave rectified AC is used for magnetization of coated and plated parts. Because particle movement, either dry or wet is noticeably slower, precautions must be taken to ensure that sufficient time is allowed for formation of indications.

11.1.4 *Direct Current (DC)* — A bank of batteries or a DC generator produce a direct magnetizing current. They have largely given way to half-wave rectified or full-wave rectified AC except for a few specialized applications, primarily because of battery cost and maintenance. One such example is the charging of a bank of capacitors, which on discharge is used to establish a residual magnetic field in tubing, casing, line pipe, and drill pipe.

12. Part Magnetization Techniques

12.1 *Examination Coverage* — All examinations should be conducted with sufficient area overlap to assure the required coverage at the specified sensitivity has been obtained.

12.2 *Direct and Indirect Magnetization* — A part can be magnetized either directly or indirectly. For direct magnetization the magnetizing current is passed directly through the part creating a circular magnetic field in the part. With indirect magnetization techniques a magnetic field is induced in the part which can create a circular/toroidal, longitudinal, or multidirectional magnetic field in the part. The techniques described in 20.8 for verifying that the magnetic fields have the anticipated direction and strength should be employed. This is especially important when using the multidirection technique to examine complex shapes.

12.3 *Choosing a Magnetization Technique* — The choice of direct or indirect magnetization will depend on such factors as size, configuration, or ease of processing. Table 1 compares the advantages and limitations of the various methods of part magnetization.

12.3.1 *Direct Contact Magnetization* — For direct magnetization, physical contact must be made between the ferromagnetic part and the current carrying elec-

TABLE 1
ADVANTAGES AND LIMITATIONS OF THE VARIOUS WAYS OF MAGNETIZING A PART

Magnetizing Technique and Material Form	Advantages	Limitations
I. Direct Contact Part Magnetization (see 12.3.1)		
Head/Tailstock Contact Solid, relatively small parts (castings, forgings, machined pieces) that can be processed on a horizontal wet unit	1. Fast, easy technique 2. Circular magnetic field surrounds current path. 3. Good sensitivity to surface and near-surface discontinuities. 4. Simple as well as relatively complex parts can usually be easily processed with one or more shots. 5. Complete magnetic path is conducive to maximizing residual characteristics of material.	1. Possibility of arc burns if poor contact conditions exist. 2. Long parts should be magnetized in sections to facilitate bath application without resorting to an overly long current shot.
Large castings and forgings	1. Large surface areas can be processed and examined in relatively short time.	1. High amperage requirements (16 000 to 20 000 A) dictate special DC power supply.
Cylindrical parts such as tubing, pipe, hollow shafts, etc.	1. Entire length can be circularly magnetized by contacting, end to end.	1. Effective field limited to outside surface and cannot be used for inside diameter examination. 2. Ends must be conductive to electrical contacts and capable of carrying required current without excessive heat. Cannot be used on oil country tubular goods because of possibility of arc burns.
Long solid parts such as billets, bars, shafts, etc.	1. Entire length can be circularly magnetized by contacting, end to end. 2. Current requirements are independent of length. 3. No end loss.	1. Voltage requirements increase as length increases due to greater impedance of cable and part. 2. Ends must be conductive to electrical contact and capable of carrying required current without excessive heat.
Prods: Welds	1. Circular field can be selectively directed to weld area by prod placement. 2. In conjunction with half-wave rectified alternating current and dry powder, provides excellent sensitivity to subsurface discontinuities as well as surface type. 3. Flexible, in that prods, cables, and power packs can be brought to examination site.	1. Only small area can be examined at one time. 2. Arc burns due to poor contact. 3. Surface must be dry when dry powder is being used. 4. Prod spacing must be in accordance with the magnetizing current level.

TABLE 1 (CONT'D)
ADVANTAGES AND LIMITATIONS OF THE VARIOUS WAYS OF MAGNETIZING A PART

Magnetizing Technique and Material Form	Advantages	Limitations
Large castings or forgings	1. Entire surface area can be examined in small increments using nominal current values. 2. Circular field can be concentrated in specific areas that historically are prone to discontinuities. 3. Equipment can be brought to the location of parts that are difficult to move. 4. In conjunction with half-wave rectified alternating current and dry powder, provides excellent sensitivity to near surface subsurface type discontinuities that are difficult to locate by other methods.	1. Coverage of large surface area requires a multiplicity of shots that can be very time-consuming. 2. Possibility of arc burns due to poor contact. Surface should be dry when dry powder is being used.
II. Indirect Part Magnetization (see 12.3.2)		
Central Conductor Miscellaneous parts having holes through which a conductor can be placed such as: Bearing race Hollow cylinder Gear Large nut Large clevis Pipe coupling, casing/tubing	1. No electrical contact to part and possibility of arc burns eliminated. 2. Circumferentially directed magnetic field is generated in all surfaces surrounding the conductor (inside diameter, faces, etc.). 3. Ideal for those cases where the residual method is applicable. 4. Light weight parts can be supported by the central conductor. 5. Multiple turns may be used to reduce current required.	1. Size of conductor must be ample to carry required current. 2. Ideally, conductor should be centrally located within hole. 3. Larger diameters require repeated magnetization with conductor against inside diameter and rotation of part between processes. Where continuous magnetization technique is being employed, examination is required after each magnetization.
Tubular type parts such as: Pipe/Casting Tubing Hollow shaft	1. No electrical contact of part required. 2. Inside diameter as well as outside diameter examination. 3. Entire length of part circularly magnetized.	1. Outside surface sensitivity may be somewhat less than that obtained on the inside surface for large diameter and extremely heavy wall.
Large valve bodies and similar parts	1. Provides good sensitivity for detection of discontinuities located on internal surfaces.	1. Outside surface sensitivity may be somewhat less than that obtained on the inside diameter for heavy wall.
Coil/Cable Wrap Miscellaneous medium-sized parts where the length predominates such as a crankshaft	1. All generally longitudinal surfaces are longitudinally magnetized to effectively locate transverse discontinuities.	1. Length may dictate multiple shot as coil is repositioned.
Large castings, forgings, or shafting	1. Longitudinal field easily attained by means of cable wrapping.	1. Multiple magnetization may be required due to configuration of part.

TABLE 1 (CONT'D)
ADVANTAGES AND LIMITATIONS OF THE VARIOUS WAYS OF MAGNETIZING A PART

Magnetizing Technique and Material Form	Advantages	Limitations
Miscellaneous small parts	1. Easy and fast, especially where residual magnetization is applicable. 2. No electrical contact. 3. Relatively complex parts can usually be processed with same ease as those with simple cross section.	1. L/D (length/diameter) ratio important consideration in determining adequacy of ampere-turns. 2. Effective L/D ratio can be altered by utilizing pieces of similar cross-sectional area. 3. Use smaller coil for more intense field. 4. Sensitivity diminishes at ends of part due to general leakage field pattern. 5. Quick break desirable to minimize end effect on short parts with low L/D ratio.
Induced Current Fixtures Examination of ring-shaped part for circumferential-type discontinuities.	1. No electrical contact. 2. All surfaces of part subjected to toroidal-type magnetic field. 3. Single process for 100% coverage. 4. Can be automated.	1. Laminated core required through ring. 2. Type of magnetizing current must be compatible with method. 3. Other conductors encircling field must be avoided. 4. Large diameters require special consideration.
Ball examination	1. No electrical contact. 2. 100% coverage for discontinuities in any direction with three-step process and proper orientation between steps. 3. Can be automated.	1. For small-diameter balls, limited to residual magnetization.
Disks and gears	1. No electrical contact. 2. Good sensitivity at or near periphery or rim. 3. Sensitivity in various areas can be varied by core or pole-piece selection.	1. 100% coverage may require two-step process with core or pole-piece variation, or both. 2. Type of magnetizing current must be compatible with part geometry.
Yokes: Examination of large surface areas for surface-type discontinuities.	1. No electrical contact. 2. Highly portable. 3. Can locate discontinuities in any direction with proper orientation.	1. Time consuming. 2. Must be systematically repositioned in view of random discontinuity orientation.
Miscellaneous parts requiring examination of localized areas.	1. No electrical contact. 2. Good sensitivity to direct surface discontinuities. 3. Highly portable. 4. Wet or dry technique. 5. Alternating-current type can also serve as demagnetizer in some instances.	1. Must be properly positioned relative to orientation or discontinuities. 2. Relatively good contact must be established between part and poles. 3. Complex part geometry may cause difficulty. 4. Poor sensitivity to subsurface-type discontinuities except in isolated areas.

trodes connected to the power source. Both localized area magnetization and overall part magnetization are direct contact means of part magnetization achieved through the use of prods, head and tailstock, clamps, and magnetic leeches.

12.3.2 *Localized Area Magnetization:*

12.3.2.1 *Prod Technique* — The prod electrodes are first pressed firmly against the test part [Fig. 2(a)]. The magnetizing current is then passed through the prods and into the area of the part in contact with the prods. This establishes a circular magnetic field in the part around and between each prod electrode, sufficient to carry out a local magnetic particle examination (Figs. 2(c) and 2(d)). **Caution:** Extreme care should be taken to maintain clean prod tips, to minimize heating at the point of contact and to prevent arc burns and local overheating on the surface being examined since these may cause adverse effects on material properties. Arc burns cause metallurgical damage; if the tips are solid copper, copper penetration into the part may occur. Prods should not be used on machined surfaces or on aerospace component parts.

(1) Unrectified AC limits the prod technique to the detection of surface discontinuities. Half-wave rectified AC is most desirable since it will detect both surface and near-surface discontinuities. The prod technique generally utilizes dry magnetic particle materials due to better particle mobility. Wet magnetic particles are not generally used with the prod technique because of potential electrical and flammability hazards.

(2) Proper prod examination requires a second placement with the prods rotated approximately 90° from the first placement to assure that all existing discontinuities are revealed. Depending on the surface coverage requirements, overlap between successive prod placements may be necessary. On large surfaces, it is good practice to layout a grid for prod/yoke placement.

12.3.2.2 *Manual Clamp/Magnetic Leech Technique* — Local areas of complex components may be magnetized by electrical contacts manually clamped or attached with magnetic leeches to the part (Fig. 4). As with prods, sufficient overlap may be necessary if testing of the contact location is required.

12.3.2.3 *Overall Magnetization:*

(1) Head and Tailstock Contact — Parts may be clamped between two electrodes (such as a head and tailstock of horizontal wet magnetic particle equipment) and the magnetizing current applied directly through the part (Fig. 5). The size and shape of the part will

FIG. 4 DIRECT-CONTACT MAGNETIZATION THROUGH MAGNETIC LEECH CLAMP OF PART

FIG. 5 DIRECT CONTACT MAGNETIZATION THROUGH HEAD/TAILSTOCK

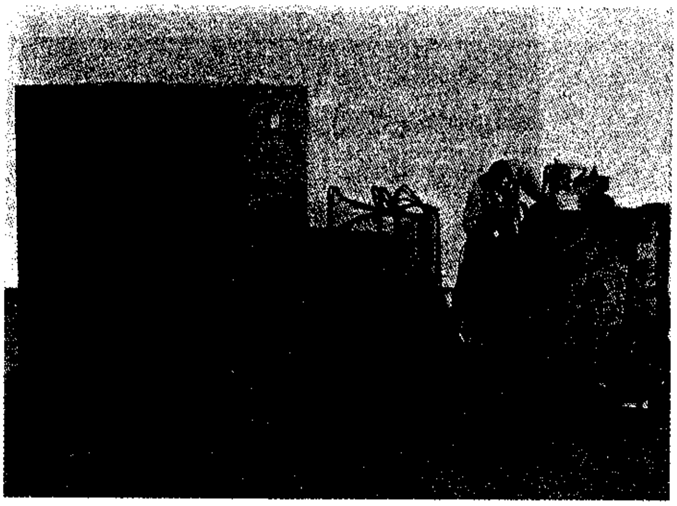


FIG. 6 DIRECT CONTACT OVERALL MAGNETIZATION

determine whether both field directions can be obtained with such equipment.

(2) Clamps — The magnetizing current may be applied to the test part by clamping the current carrying electrodes to the part, producing a circular magnetic field (Fig. 6).

(3) Multidirectional Magnetization Technique — With suitable circuitry, it is possible to produce a multidirectional (oscillating) field in a part by selectively switching the magnetic field within the part between electrode contacts/clamps positioned approximately 90 deg. apart. This permits building up indications in all possible directions and may be considered the equivalent of magnetizing in two or more directions (Fig. 7). On some complex shapes as many as 16 to 20 steps may be required with conventional equipment. With multidirectional magnetization, it is usually possible to reduce the magnetizing steps required by more than half. It is essential that the wet continuous method be used and that the magnetic field direction and relative intensity be determined by one or more of the techniques described in 20.8.

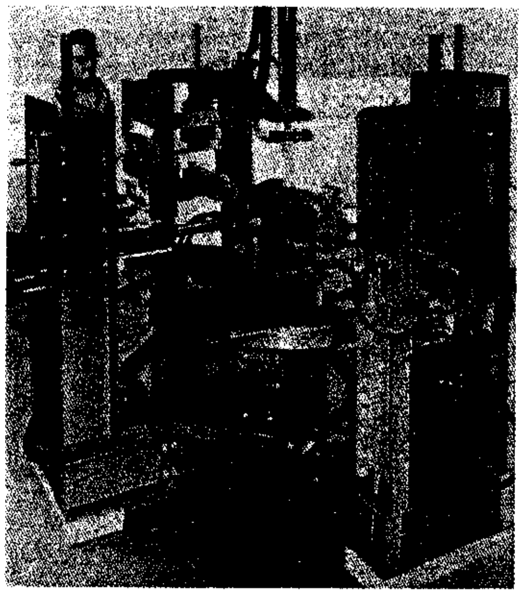


FIG. 7 MULTIDIRECTIONAL-OVERALL MAGNETIZATION

12.3.3 *Indirect Magnetization* — Indirect part magnetization involves the use of a preformed coil, cable wrap, yoke, or a central conductor to induce a magnetic field. Coil, cable wrap, and yoke magnetization are referred to as longitudinal magnetization in the part (see 13.3).

12.3.3.1 *Coil and Coil Magnetization* — When coil (Fig. 3) or cable wrap (Fig. 8) techniques are used, the magnetic field strength is proportional to ampere turns and depends on simple geometry (see 14.3.2).

12.3.3.2 *Central Conductor, Induced Current Magnetization* — Indirect circular magnetization of

FIG. 8 CABLE MAGNETIZATION

hollow pieces/parts can be performed by passing the magnetizing current through a central conductor [Figs. 9(a) and 9(b)] or cable used as a central conductor or through an induced current fixture [Fig. 9(c)].

12.3.3.3 *Yoke Magnetization* — A magnetic field can be induced into a part by means of an electromagnet (see Fig. 1), where the part or a portion thereof becomes the magnetic path between the poles (acts as a keeper) and discontinuities preferentially transverse to the alignment of the pole pieces are indicated. Most yokes are energized by AC, half-wave rectified AC, or full-wave rectified AC. A permanent magnet can also introduce a magnetic field in the part but its use is restricted (see 6.3.1).

13. Direction of Magnetic Fields

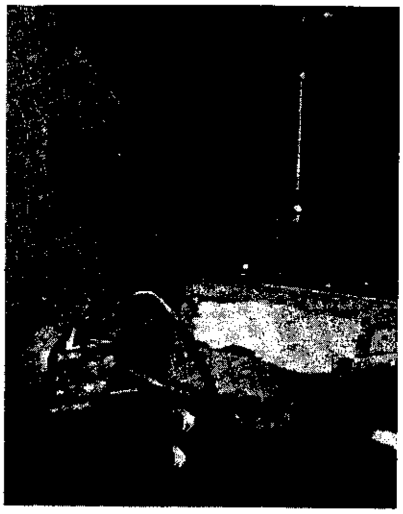
13.1 *Discontinuity Orientation vs. Magnetic Field Direction* — Since indications are not normally obtained when discontinuities are parallel to the magnetic field, and since indications may occur in various or unknown directions in a part, each part must be magnetized in at least two directions approximately at right angles to each other as noted in 5.3.2. On some parts circular magnetization may be used in two or more directions, while on others both circular and longitudinal magnetization are used. A multidirectional field can also be employed to achieve part magnetization in more than one direction.

13.2 *Circular Magnetization* — Circular magnetization (Fig. 10) is the term used when electric current is passed through a part, or by use of a central conductor (see 12.3.3.2) through a central opening in the part, inducing a magnetic field at right angles to the current flow.

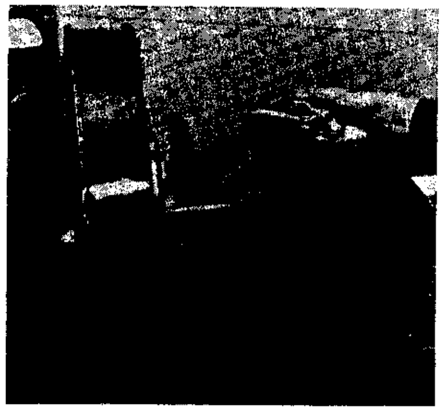
13.3 *Toroidal Magnetization* — When magnetizing a part with a toroidal shape, such as a solid wheel or the disk with a center opening, an induced field that is radial to the disk is most useful for the detection of discontinuities in a circumferential direction. In such applications this field may be more effective than multiple shots across the periphery.

13.4 *Longitudinal Magnetization* — Longitudinal magnetization (Fig. 11) is the term used when a magnetic field is generated by an electric current passing through a multiturn, Fig. 12, or laminated coil, Fig. 13, which encloses the part or section of the part to be examined.

13.5 *Multidirectional Magnetization* — The magnetic fields may be induced in the part by passing current through the part from different directions (see 12.3.2.3 and Fig. 14). Artificial flaws, circular shims, or known defects should be used to establish magnetic field direction.



(*a*) Use of Central Conductor on Multipart Magnetization



(*b*) Use of Central Conductor for Localized Magnetization

(*c*) Use of a Special Induced Current Fixture

FIG. 9 CENTRAL CONDUCTOR INDUCED MAGNETIZATION

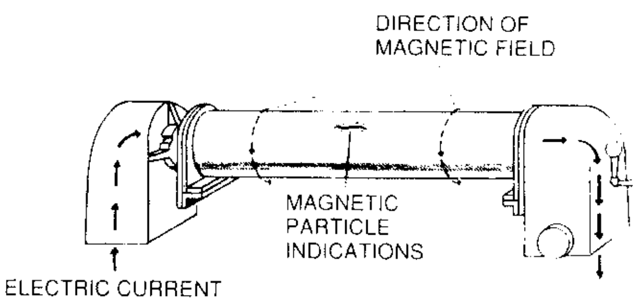


FIG. 10 CIRCULAR MAGNETIZATION

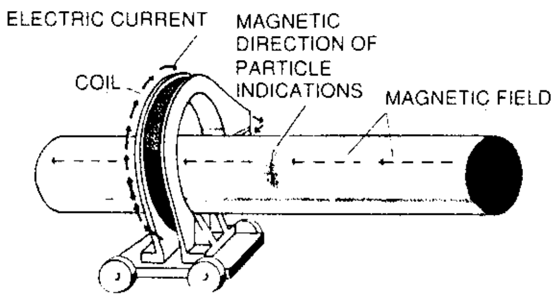


FIG. 11 LONGITUDINAL MAGNETIZATION

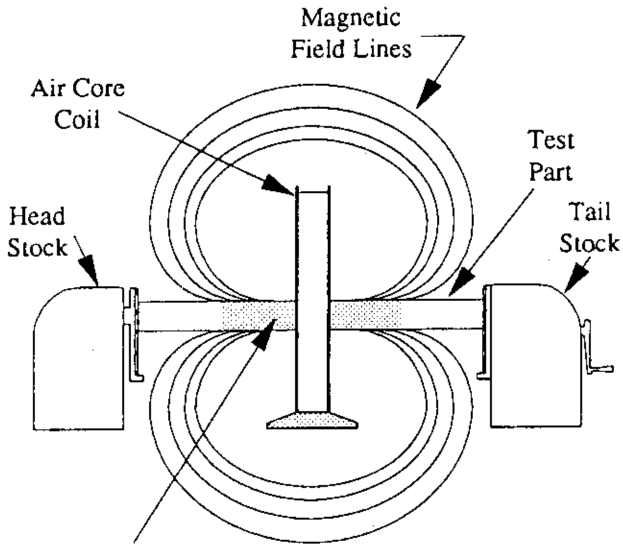


FIG. 12 MAGNETIC FIELD PRODUCED BY AN AIR CORE COIL

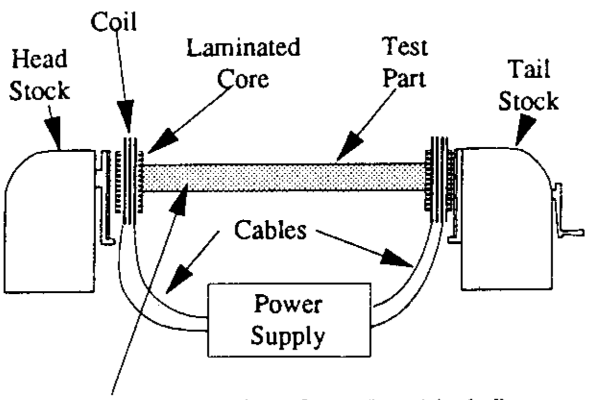


FIG. 13 MAGNETIC FIELD PRODUCED BY A LAMINATED CORE COIL

14. Magnetic Field Strength

14.1 *Magnetizing Field Strengths* — To produce interpretable indications, the magnetic field in the part must have sufficient strength and proper orientation. For the indications to be consistent, this field strength must be controlled within reasonable limits, usually ±25%. Factors that affect the strength of the field are the size, shape, section thickness, material of the part/piece, and the technique of magnetization. Since these factors vary widely, it is difficult to establish rigid rules for magnetic field strengths for every conceivable configuration.

14.2 *Establishing Field Strengths* — Sufficient magnetic field strength can be established by:

14.2.1 *Known Discontinuities* — Experiments with similar/identical parts having known discontinuities.

14.2.2 *Artificial Discontinuities* — The ''pie'' field indicator (Fig. 15) and slotted shims (Fig. 16) are artificial discontinuities. See 20.8.

14.2.3 *Hall-effect Probe-Tangential Field Strengths* — Tangentially applied field strengths, as measured with a Hall-effect probe/sensor, in the range from 30 to 60 G (2.4 to 4.8 kAM^{-1}) should be adequate. See 20.8. Under some circumstances some fields in the range from 10 to 150 G may be required.

14.2.4 *Using Empirical Formulas* — Section 14.3 has four empirical formulas for establishing magnetic field strengths; they are rules of thumb. As such, they must be used with judgment. Their use may lead to:

14.2.4.1 Over magnetization, which causes excessive particle background that makes interpretation more difficult if not impossible.

14.2.4.2 Poor coverage.

14.2.4.3 Poor choice of test geometries.

14.2.4.4 A combination of the above.

14.3 *Guidelines for Establishing Magnetic Fields* — The following guidelines can be effectively applied for establishing proper levels of circular and longitudinal magnetization.

14.3.1 *Circular Magnetization — Magnetic Field Strength:*

14.3.1.1 *Central Conductor Induced Magnetization* — Central conductors are widely used in magnetic particle examination to provide:

(1) A circular field on both the inside surface and outside surface of tubular pieces that cannot be duplicated by the direct current technique.

(2) A non-contact means of part magnetization virtually eliminating the possibility of arc burning the material, as can be the case with current flow through contacts, such as prods or clamps.

FIG. 14 MULTIDIRECTIONAL MAGNETIZATION

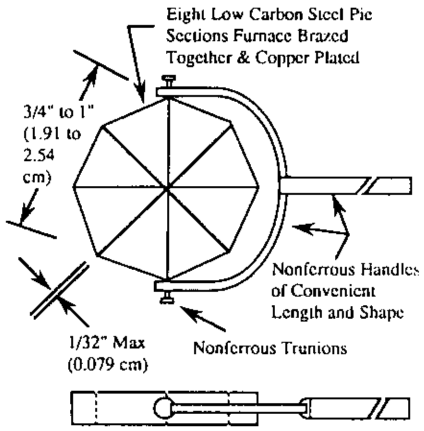
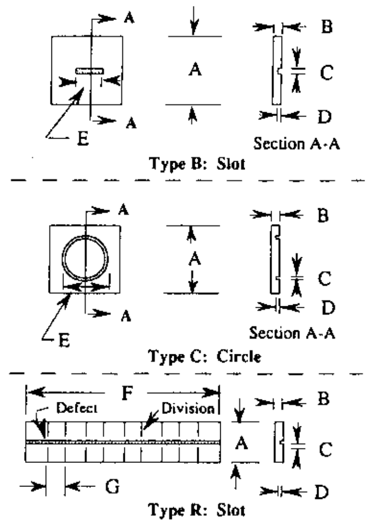


FIG. 15 MAGNETIC FIELD INDICATOR

(3) Substantial processing advantages over direct contact techniques on ring-shaped parts.

(4) In general it is desirable to centrally locate a central conductor to permit the entire circumference of the part to be processed at one time. The resulting field is concentric relative to the axis of the piece and is maximum at the inside surface. The strength of the magnetic field should be verified by the means discussed in 20.8. With a centrally located central conductor, the magnetizing current requirements would be the same as a solid piece having the same outside diameter.



Item	Dimension	Tolerance
A	(1)	± 1 mm
B	0.05 mm	± 0.0001 mm
C	0.005 mm	± 0.0001 mm
D	See 20.4.2	± 0.0001 mm
E	(1)	± 1mm
F	(1)	± 1 mm
G	(1)	± 1mm

(1) As specified by the manufacturer. These dimensions are not critical, see 20.4.8.

FIG. 16 TYPICAL SLOTTED SHIM DESIGNS

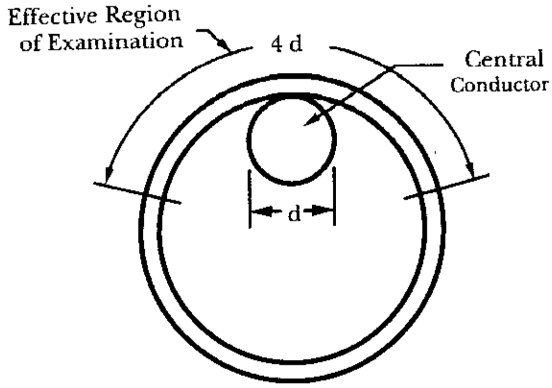


FIG. 17 APPROXIMATE EFFECTIVE REGION OF EXAMINATION WHEN USING AN OFFSET CENTRAL CONDUCTOR (THREADER BAR)

(5) When using offset central conductors the conductor passing through the inside of the part is placed against an inside wall of the part. The current shall be from 12 A per mm of part diameter to 32 A per mm of part diameter (300 to 800 A/in.). The diameter of the part shall be taken as the largest distance between any two points on the outside circumference of the part. Generally currents will be 500 A/in. (20 A per mm) or lower with the higher currents (up to 800 A/in.) being used to examine for inclusions or to examine low permeability alloys such as precipitation-hardening steels. For examinations used to locate inclusions in precipitation-hardening steels even higher currents, up to 1000 A/in. (40 A per mm) may be used. The distance along the part circumference which may be effectively examined shall be taken as approximately four times the diameter of the central conductor, as illustrated Fig. 17. The entire circumference shall be examined by rotating the part on the conductor, allowing for approximately a 10% magnetic field overlap. Less overlap, different current levels, and larger effective regions (up to 360°) may be used if the presence of suitable field levels is verified.

14.3.1.2 Localized Magnetization:

(1) Using Prods — With prods, the strength circular magnetization is proportional to the amperage used but varies with the prod spacing and thickness of the section being examined. It is recommended that a magnetizing current from 1 in. (90 to 110 A/25 mm) of prod spacing should be used for material $\frac{3}{4}$ in. (19 mm) and over in thickness. Prolonged energizing cycles may cause undesirable localized overheating. Prod spacing should not exceed 8 in. (200 mm). Prod spacing less than 3 in. (75 mm) is usually not practical due to banding of the particles around the prods. When the area of examination exceeds a width of one quarter of the prod spacing, measured from a centerline connecting the prod centers, the magnetic field intensity should be verified at the edges of the area being examined.

(2) Using Yokes — The field strength of a yoke (or a permanent magnet) can be empirically determined by measuring its lifting power (see 20.3.6). If a Hall-effect probe is used, it shall be placed on the surface midway between the poles.

14.3.2 *Air-Core Coil Longitudinal Magnetization* — Longitudinal part magnetization is produced by passing a current through a multiturn coil encircling the part or section of the part to be examined. A magnetic field is produced parallel to the axis of the coil. The unit of measurement is ampere turns (NI) (the actual amperage multiplied by the number of turns in the encircling coil or cable). The effective field extends on either side of the coil a distance approximately equal to the radius of the coil being employed. Long parts should be examined in sections not to exceed this length. There are four empirical longitudinal magnetization formulas employed for using encircling coils, the formula to be used depending on the fill factor. The formulas are included for historical continuity only. If used its use should be limited to simple shaped parts. It would be quicker and more accurate to use a Gauss (Tesla) meter, lay its probe on the part and measure the field rather than to calculate using the formulas.

14.3.2.1 *Low Fill-Factor Coils* — In this case, the cross-sectional area of the fixed encircling coil greatly exceeds the cross-sectional area of the part (less than 10% coil inside diameter). For proper part magnetization, such parts should be placed well within the coils and close to the inside wall of the coil. With this low fill-factor, adequate field strength for eccentrically positioned parts with a length-over-diameter ratio (*L/D*) between 3 and 15 is calculated from the following equations:

(1) Parts With Low Fill-Factor Positioned Close to Inside Wall of Coil:

$$NI = K/(L/D)(\pm 10\%) \tag{1}$$

where:

N = number of turns in the coil,
I = coil current to be used, amperes (A),
K = 45 000 (empirically derived constant),
L = part, length, in., (see Note),

D = part diameter, in.; for hollow parts, see 14.3.2.4, and
NI = ampere turns.

For example, a part 15 in. (38.1 cm) long with 5-in. (12.7-cm) outside diameter has an L/D ratio of 15/5 or 3. Accordingly, the ampere turn requirement (NI = 45 000/3) to provide adequate field strength in the part would be 15 000 ampere turns. If a five-turn coil or cable is used, the coil amperage requirements would be (I = 15 000/5) = 3000 A (±10%). A 500 turn coil would require 30 A (±10%).

(2) Parts with a Low Fill-Factor Positioned in the Center of the Coil:

$$NI = KR/\{(6L/D) - 5\}(\pm 10\%) \qquad (2)$$

where:

N = number of turns in the coil,
I = coil current to be used, A,
K = 43 000 (empirically derived constant),
R = coil radius, in.,
L = part length, in. (see Note),
D = part diameter, in., for hollow parts (see 14.3.2.4), and
NI = ampere turns.

For example, a part 15 in. (38.1 cm) long with 5-in. (12.7-cm) outside diameter has a L/D ratio of 15/5 or 3. If a five-turn 12-in. diameter (6-in. radius) (30.8-cm diameter [15.4-cm radius)] coil or cable is used, (*1*) the ampere turns requirement would be as follows:

$$NI = \frac{(43\,000 \times 6)}{[(6 \times 3) - 5]} \text{ or } 19\,846$$

and (*2*) the coil amperage requirement would be as follows:

$$\frac{19\ 846}{5} \text{ or } 3\,969 \text{ A } (\pm 10\%)$$

14.3.2.2 *Intermediate Fill-Factor Coils* — When the cross section of the coil is greater than twice and less than ten times the cross section of the part being examined:

$$NI = (NI)_{hf}\,(10 - Y) + (NI)_{lf}\,(Y - 2)/8 \qquad (3)$$

where:

NI_{hf} = value of NI calculated for high fill-factor coils using Eq 4,
NI_{lf} = value of NI calculated for low fill-factor coils using Eq 1 or Eq 2, and
Y = ratio of the cross-sectional area of the coil to the cross section of the part. For example, if the coil has an inside diameter of 10 in. (25.4 cm) and part (a bar) has an outside diameter of 5 in. (12.2 cm)

$$Y = [\pi(5)^2]/[\pi(2.5)^2] = 4$$

14.3.2.3 *High Fill-Factor Coils* — In this case, when fixed coils or cable wraps are used and the cross-sectional area of the coil is less than twice the cross-sectional area (including hollow portions) of the part, the coil has a high fill-factor.

(*1*) For Parts Within a High Fill-Factor Positioned Coil and for Parts with an L/D ratio equal to or greater than 3:

$$NI = \frac{K}{\{(L/D) + 2\}}(\pm 10\%) \qquad (4)$$

where:

N = number of turns in the coil or cable wrap.
I = coil current, A,
K = 35 000 (empirically derived constant),
L = part length, in.,
D = part diameter, in., and
NI = ampere turns.

For example, the application of Eq 4 can be illustrated as follows: a part 10 in. (25.4 cm) long-with 2-in. (5.08-cm) outside diameter would have an L/D ratio of 5 and an ampere turn requirements of NI = 35 000/ (5 + 2) or 5000 (±10%) ampere turns. If a five-turn coil or cable wrap is employed, the amperage requirement is 5000/5 or 1000 A (±10%).

NOTE — For L/D ratios less than 3, a pole piece (ferromagnetic material approximately the same diameter as part) should be used to effectively increase the L/D ratio or utilize an alternative magnetization method such as induced current. For L/D ratios greater than 15, a maximum L/D value of 15 should be used for all formulas cited above.

14.3.2.4 *L/D Ratio for a Hollow Piece* — When calculating the L/D ratio for a hollow piece, D shall be replaced with an effective diameter D_{eff} calculated using:

$$D_{eff} = [(A_t - A_h)/\pi]^{1/2}$$

where:

A_t = total cross-sectional area of the part, and
A_h = cross-sectional area of the hollow portion(s) of the part.

For a cylindrical piece, this is equivalent to:

$$D_{eff} = [(OD)^2 - (ID)^2]^{1/2}$$

where:

OD = outside diameter of the cylinder, and
ID = inside diameter of the cylinder.

15. Application of Dry and Wet Magnetic Particles

15.1 *Dry Magnetic Particles:*

15.1.1 *Magnetic Fields for Dry Particles* — Dry magnetic powders are generally applied with the continuous magnetizing techniques utilizing AC or half-wave rectified AC or yoke magnetization. A current duration of at least $\frac{1}{2}$ s should be used. The current duration should be short enough to prevent any damage from overheating or from other causes. It should be noted that AC and half-wave rectified AC impart better particle mobility to the powder than DC or full-wave rectified AC. Dry magnetic powders are widely used for magnetic particle examination of large parts as well as on localized areas such as welds. Dry magnetic particles are widely used for oil field applications and are frequently used in conjunction with capacitor discharge style equipment and the residual method.

15.1.2 *Dry Powder Application* — Dry powders should be applied in such a manner that a light uniform, dust-like coating settles upon the surface of the part/piece while it is being magnetized. Dry particles must not be applied to a wet surface; they will have limited mobility. Neither should they be applied where there is excessive wind. The preferred application technique suspends the particles in air in such a manner that they reach the part surface being magnetized in a uniform cloud with a minimum of force. Usually, specially designed powder blowers and hand powder applicators are employed. (Figs. 1b and 4). Dry particles should not be applied by pouring, throwing, or spreading with the fingers.

15.1.3 *Excess Powder Removal* — Care is needed in both the application and removal of excess dry powder. While the magnetizing current is present, care must be exercised to prevent the removal of particles attracted by a leakage field that may prove to be a relevant indication of a discontinuity.

15.1.4 *Near-surface Discontinuities Powder Patterns* — In order to recognize the broad, fuzzy, weakly held powder patterns produced by near-surface discontinuities, it is essential to observe carefully the formation of indications while the powder is being applied and also while the excess is being removed. Sufficient time for indication formation and examination should be allowed between successive magnetization cycles.

15.2 *Wet Particle Application* — Wet magnetic particles, fluorescent or nonfluorescent, suspended in a vehicle at a recommended concentration may be applied either by spraying or flowing over the areas to be inspected during the application of the magnetizing field current (continuous technique) or after turning off the current (residual technique). Proper sequencing of operation (part magnetization and timing of bath application) is essential to indication formation and retention. For the continuous technique multiple current shots should be applied. The last shot should be applied after the particle flow has been diverted and while the particle bath is still on the part. A single shot may be sufficient. Care should be taken to prevent damage to a part due to overheating or other causes. Since fine or weakly held indications on highly finished or polished surfaces may be washed away or obliterated, care must be taken to prevent high-velocity flow over critical surfaces and to cut off the bath application before removing the magnetic field. Since a residual field has a lower intensity than a continuous field, less pronounced indications tend to form.

15.3 *Magnetic Slurry/Paints* — Magnetic slurry/paints are applied to the part with a brush before or during part magnetization. Indications appear as a dark line against a light silvery background. Magnetic slurry is ideal for overhead or underwater magnetic particle examination.

15.4 *Magnetic Polymers* — Magnetic polymers are applied to the test part as a liquid polymer suspension. The part is then magnetized, the polymer is allowed to cure, and the elastic coating is removed from the test surface for examination. Care must be exercised to ensure that magnetization is completed within the active migration period of the polymer which is usually about 10 min. This method is particularly applicable to areas of limited visual access such as bolt holes. Detailed application and use instructions of the manufacturer should be followed for optimum results.

16. Interpretation of Indications

16.1 *Valid Indications* — All valid indications formed by magnetic particle examination are the result of magnetic leakage fields. Indications may be relevant (16.1.1), nonrelevant (16.1.2), or false (16.1.3).

16.1.1 *Relevant Indications* — Relevant indications are produced by leakage fields which are the result of discontinuities. Relevant indications require evaluation with regard to the acceptance standards agreed upon between the manufacturer/test agency and the purchaser (see Annex A1).

16.1.2 *Nonrelevant Indications* — Nonrelevant indications can occur singly or in patterns as a result of leakage fields created by conditions that require no evaluation such as changes in section (like keyways and drilled holes), inherent material properties (like the edge of a bimetallic weld), magnetic writing, etc.

16.1.3 *False Indications* — False indications are not the result of magnetic forces. Examples are particles held mechanically or by gravity in shallow depressions or particles held by rust or scale on the surface.

17. Recording of Indications

17.1 *Means of Recording* — When required by a written procedure, permanent records of the location, type, direction, length(s), and spacing(s) of indications may be made by one or more of the following means.

17.1.1 *Sketches* — Sketching the indication(s) and their locations.

17.1.2 *Transfer (Dry Powder Only)* — Covering the indication(s) with transparent adhesive-backed tape, removing the tape with the magnetic particle indication(s) adhering to it, and placing it on paper or other appropriate background material indicating locations.

17.1.3 *Strippable Film (Dry Powder Only)* — Covering the indication(s) with a spray-on strippable film that fixes the indication(s) in place. When the film is stripped from the part, the magnetic particle indication(s) adhere to it.

17.1.4 *Photographing* — Photographing the indications themselves, the tape, or the strippable film reproductions of the indications.

17.1.5 *Written Records* — Recording the location, length, orientation, and number of indications.

17.2 *Accompanying Information* — A record of the procedure parameters listed below as applicable should accompany the inspection results:

17.2.1 *Method Used* — Magnetic particle method (dry, wet, fluorescent, etc.).

17.2.2 *Magnetizing Technique* — Magnetizing technique (continuous, true-continuous, residual).

17.2.3 *Current Type* — Magnetizing current (AC, half-wave rectified or full-wave rectified AC, etc.).

17.2.4 *Field Direction* — Direction of magnetic field (prod placement, cable wrap sequence, etc.).

17.2.5 *Field Strength* — Magnetic current strength [ampere turns, amperes per millimetre (inch) of prod spacing, lifting force, etc.].

18. Demagnetization

18.1 *Applicability* — All ferromagnetic material will retain some residual magnetism, the strength of which is dependent on the retentivity of the part. Residual magnetism does not affect the mechanical properties of the part. However, a residual field may cause chips, filing, scale, etc. to adhere to the surface affecting subsequent machining operations, painting, or plating. Additionally, if the part will be used in locations near sensitive instruments, high residual fields could affect the operation of these instruments. Furthermore, a strong residual magnetic field in a part to be arc welded could interfere with welding. Residual fields may also interfere with later magnetic particle examination. Demagnetization is required only if specified in the drawings, specification, or purchase order. When required, an acceptable level of residual magnetization and the measuring method shall also be specified. See 18.3.

18.2 *Demagnetization Methods* — The ease of demagnetization is dependent on the coercive force of the metal. High retentivity is not necessarily related to high coercive force in that the strength of the residual field is not always an indicator of ease of demagnetizing. In general, demagnetization is accomplished by subjecting the part to a field equal to or greater than that used to magnetize the part and in nearly the same direction, then continuously reversing the field direction while gradually decreasing it to zero.

18.2.1 *Withdrawal from Alternating Current Coil* — The fastest and most simple technique is to pass the part through a high intensity alternating current coil and then slowly withdraw the part from the field of the coil. A coil of 5000 to 10 000 ampere turns is recommended. Line frequency is usually from 50 to 60 Hz alternating current. The piece should enter the coil from a 12-in. (300-mm) distance and move through it steadily and slowly until the piece is at least 36 in. (900 mm) beyond the coil. Care should be exercised to ensure that the part is entirely removed from the influence of the coil before the demagnetizing force is discontinued, otherwise the demagnetizer may have the reverse effect of magnetizing the part. This should be

repeated as necessary to reduce the residual field to an acceptable level. See 18.3. Small parts of complex figuration can be rotated and tumbled while passing through the field of the coil.

18.2.2 *Decreasing Alternating Current* — An alternative technique for part demagnetization is subjecting the part to the field while gradually reducing its strength to a desired level.

18.2.3 *Demagnetizing With Yokes* — Alternating current yokes may be used for local demagnetization by placing the poles on the surface, moving them around the area, and slowly withdrawing the yoke while it is still energized.

18.2.4 *Reversing Direct Current* — The part to be demagnetized is subjected to consecutive steps of reversed and reduced direct current magnetization to a desired level. (This is the most effective process of demagnetizing large parts in which the alternating current field has insufficient penetration to remove the internal residual magnetization.) This technique requires special equipment for reversing the current while simultaneously reducing it in small increments.

18.3 *Extent of Demagnetization* — The effectiveness of the demagnetizing operation can be indicated by the use of appropriate magnetic field indicators or field strength meters. **Caution:** A part may retain a strong residual field after having been circularly magnetized and exhibit little or no external evidence of this field. Therefore, the circular magnetization should be conducted before longitudinal magnetization if complete demagnetization is required.

18.3.1 After demagnetization residual fields should not exceed 3 G (240 Am^{-1}) anywhere in the piece, absolute value, unless otherwise agreed upon or as specified on the engineering drawing or in the contract, purchase order, or specification.

19. Post Examination Cleaning

19.1 *Particle Removal* — Post-test cleaning is necessary where magnetic particle material(s) could interfere with subsequent processing or with service requirements. The purchaser should specify when post-test cleaning is needed and the extent required.

19.2 *Means of Particle Removal* — Typical post-test cleaning techniques employed are: (a) the use of compressed air to blow off unwanted dry magnetic particles; (b) drying of wet particles and subsequent removal by brushing or with compressed air; (c) removal of wet particles by flushing with solvent; and (d) other suitable post-examination cleaning techniques may be used if they will not interfere with subsequent requirements.

20. Evaluation of System Performance/Sensitivity

20.1 *Contributing Factors* — The overall performance/sensitivity of a magnetic particle examination system is dependent upon the following:

20.1.1 Operator capability, if a manual operation is involved.

20.1.2 Control of process steps.

20.1.3 The particles or suspension, or both.

20.1.4 The equipment.

20.1.5 Visible light level.

20.1.6 Black light monitoring where applicable.

20.1.7 Magnetic field strength.

20.1.8 Field direction of orientation.

20.1.9 Residual field strength.

20.1.10 These factors should all be controlled individually.

20.2 *Maintenance and Calibration of Equipment* — The magnetic particle equipment employed should be maintained in proper working order at all times. The frequency of verification calibration, usually every six months, see Table 2, or whenever a malfunction is suspected, should be specified in the written procedures of the testing facility. Records of the checks and results provide useful information for quality control purposes and should be maintained. In addition, any or all of the tests described should be performed whenever a malfunction of the system is suspected. Calibration tests should be conducted in accordance with the specifications or documents that are applicable.

20.3 *Equipment Checks* — The following tests are recommended for ensuring the accuracy of magnetic particle magnetizing equipment.

20.3.1 *Ammeter Accuracy* — The equipment meter readings should be compared to those of a control test meter incorporating a shunt or current transformer connected to monitor the output current. The accuracy of the entire control test meter arrangement should be verified at six-month intervals or as agreed upon between the purchaser and supplier by a means traceable to the National Institute of Standards and Technology (NIST). Comparative readings shall be taken at a minimum of

TABLE 2
RECOMMENDED VERIFICATION INTERVALS

Item	Maximum Time Between Verifications[A]	Reference Paragraphs
Lighting:		
Visible light intensity	1 week	7.1.1
Black light intensity	1 week	7.1.2
Background visible light intensity	1 week	7.1.1
System performance using test piece or ring specimen of Fig. 18	1 day	20.8.3
Wet particle concentration	8 h. or every shift change	20.6
Wet particle contamination	1 week	20.6.4
Water break test	1 day	20.7.3
Equipment calibration/check:		
Ammeter accuracy	6 months	20.3.1
Timer control	6 months	20.3.2
Quick break	6 months	20.3.3
Dead weight check	6 months	20.3.6
Light meter checks	6 months	20.4

[A] NOTE — The maximum time between verifications may be extended when substantiated by actual technical stability/reliability data.

three output levels encompassing the usable range. The equipment meter reading shall not deviate by more than ±10% of full scale relative to the actual current values as shown by the test meter. **Caution:** When measuring half-wave rectified AC, the direct current reading of a conventional DC test meter reading must be doubled.

20.3.2 *Timer Control Check* — On equipment utilizing a timer to control the duration of the current flow, the timer should be checked for accuracy as specified in Table 2 or whenever a malfunction is suspected.

20.3.3 *Magnetic Field Quick Break Check* — On equipment that has a quick break feature, the functioning of this circuit should be checked and verified. This test may be performed using a suitable oscilloscope or a simple test device usually available from the manufacturer. On electronic power packs or machines, failure to achieve indication of a "quick break" would indicate that a malfunction exists in the energizing circuit.

20.3.4 *Equipment Current Output Check* — To ensure the continued accuracy of the equipment, ammeter readings at each transformer tap should be made with a calibrated ammeter-shunt combination. This accessory is placed in series with the contacts. The equipment shunt should not be used to check the

TABLE 3
MINIMUM YOKE LIFTING FORCE

Type Current	Yoke Pole Leg Spacing: 50 to 100 mm (2 to 4 in.)	100 to 150 mm (4 to 6 in.)
AC	45 N (10 lb)	
DC	135 N (30 lb)	225 N (50 lb)

machine of which it is a part. For infinite current control units (non-tap switch), settings at 500-A intervals should be used. Variations exceeding ±10% from the equipment ammeter readings indicate the equipment needs service or repair.

20.3.5 *Internal Short Circuit Check* — Magnetic particle equipment should be checked periodically for internal short circuiting. With the equipment set for maximum amperage output, any deflection of the ammeter when the current is activated with no conductor between the contacts is an indication of an internal short circuit.

20.3.6 *Electromagnetic Yoke Lifting Force Test* — The magnetizing force of a yoke (or a permanent magnet) should be tested by determining its lifting power on a steel plate. See Table 3. The lifting force relates to the electromagnetic strength of the yoke.

20.3.7 *Powder Blower* — The performance of powder blowers used to apply the dry magnetic particles should be checked at routine intervals or whenever a malfunction is suspected. The check should be made on a representative test part. The blower should coat the area under test with a light, uniform dust-like coating of dry magnetic particles and have sufficient force to remove the excess particles without disturbing those particles that are evidence of indications. Necessary adjustments to the blower's flow rate or air velocity should be made in accordance with the manufacturer's recommendations.

20.4 *Examination Area Light Level Control:*

20.4.1 *Visible Light Intensity* — Light intensity in the examination area should be checked at specified intervals with the designated light meter at the surface of the parts being examined. See Table 2.

20.4.2 *Black (ultraviolet) Light Intensity* — Black light intensity and wavelength should be checked at the specified intervals but not to exceed one-week intervals and whenever a bulb is changed. Reflectors and filters should be cleaned daily and checked for

integrity. See Table 2. Cracked or broken UV filters shall be replaced immediately. Defective bulbs which radiate UV energy must also be replaced before further use.

20.5 *Dry Particle Quality Control Tests* — In order to assure uniform and consistent performance from the dry magnetic powder selected for use, it is advisable that all incoming powders be certified or tested for conformance with quality control standards established between the user and supplier.

20.5.1 *Contamination:*

20.5.1.1 *Degradation Factors* — Dry magnetic particles are generally very rugged and perform with a high degree of consistency over a wide process envelope. Their performance, however, is susceptible to degradation from such contaminants as moisture, grease, oil, rust and mill scale particles, nonmagnetic particles such as foundry sand, and excessive heat. These contaminants will usually manifest themselves in the form of particle color change and particle agglomeration, the degree of which will determine further use of the powder. Over-heated dry particles can lose their color, thereby reducing the color contrast with the part and thus hinder part examination. Particle agglomeration can reduce particle mobility during processing, and large particle agglomerates may not be retained at an indication.

20.5.1.2 *Ensuring Particle Quality* — To ensure against deleterious effects from possible contaminants, it is recommended that a routine performance/sensitivity test be conducted (see 20.8.3).

20.6 *Wet Particle Quality Control Tests* — The following tests for wet magnetic particle suspensions should be conducted at startup and at regular intervals to assure consistent performance. See Table 2. Since bath contamination will occur as the bath is used, monitoring the working bath at regular intervals is essential.

20.6.1 *Determining Bath Concentration* — Bath concentration and sometimes bath contamination are determined by measuring its settling volume through the use of a Test Method D 96 pear-shaped centrifuge tube with a 1-mL stem (0.05-mL divisions) for fluorescent particle suspensions or a 1.5-mL stem (0.1-mL divisions) for nonfluorescent suspensions. Before sampling, the suspension should be run through the recirculating system for at least 30 min to ensure thorough mixing of all particles which could have settled on the sump screen and along the sides or bottom of the tank. Take a 100-mL portion of the suspension from the hose or nozzle, demagnetize and allow it to settle for approximately 60 min with petroleum distillate suspensions or 30 min with water-based suspensions before reading. The volume settling out at the bottom of the tube is indicative of the particle concentration in the bath.

20.6.2 *Sample Interpretation* — If the bath concentration is low in particle content, add a sufficient amount of particle materials to obtain the desired concentration; if the suspension is high in particle content, add sufficient vehicle to obtain the desired concentration. If the settled particles appear to be loose agglomerates rather than a solid layer, take a second sample. If still agglomerated, the particles may have become magnetized; replace the suspension.

20.6.3 *Settling Volumes* — For fluorescent particles, the recommended settling volume (see 8.4.6) is from 0.1 to 0.4 mL in a 100-mL bath sample and from 1.2 to 2.4 mL per 100 mL of vehicle for nonfluorescent particles unless otherwise specified by the particle manufacturer.

20.6.4 *Bath Contamination* — Both fluorescent and nonfluorescent suspensions should be checked periodically for contaminants such as dirt, scale, oil, lint, loose fluorescent pigment, water (in the case of oil suspensions), and particle agglomerates which can adversely affect the performance of the magnetic particle examination process. See Table 2.

20.6.4.1 *Carrier Contamination* — For fluorescent baths, the liquid directly above the precipitate should be examined with black light. The liquid will have a little fluorescence. Its color can be compared with a freshly made-up sample using the same materials or with an unused sample from the original bath that was retained for this purpose. If the "used" sample is noticeably more fluorescent than the comparison standard, the bath should be replaced.

20.6.4.2 *Particle Contamination* — The graduated portion of the tube should be examined under black light if the bath is fluorescent and under visible light (for both fluorescent and nonfluorescent particles) for striations or bands, differences in color or appearance. Bands or striations may indicate contamination. If the total volume of the contaminates, including bands or striations exceeds 30% of the volume of magnetic particles, or if the liquid is noticeably fluorescent (see 20.6.4.1), the bath should be replaced.

20.6.5 *Particle Durability* — The durability of both the fluorescent and nonfluorescent magnetic particles in suspension should be checked periodically to ensure that the particles have not degraded due to chemical attack from the suspending oil or conditioned water vehicles or mechanically degraded by the rotational forces of the recirculating pump in a wet horizontal magnetic particle unit. Fluorescent magnetic particle breakdown in particular can result in a decrease in sensitivity and an increase in nonmagnetic fluorescent background. Lost fluorescent pigment can produce false indications that can interfere with the examination process.

20.6.6 *Fluorescent Brightness* — It is important that the brightness of fluorescent magnetic particle powder be maintained at the established level so that indication and background brightness can be kept at a relatively constant level. Variations in contrast can noticeably affect test results. Lack of adequate contrast is generally caused by:

20.6.6.1 An increase in contamination level of the vehicle increasing background fluorescence, or

20.6.6.2 Loss of vehicle because of evaporation, increasing concentration, or

20.6.6.3 Degradation of fluorescent particles. A change in contrast ratio can be observed by using a test ring specimen with an etched surface.

20.6.7 *Performance/Sensitivity* — Failure to find a known discontinuity in a part or obtain the specified indications on the test ring (see 20.8.3) indicates a need for changing of the entire bath. If a part was used, it must have been ultrasonically cleaned so that no fluorescent background can be detected when viewed under black light with a surface intensity of at least 100 $\mu W/cm^2$. If any background is noted that interferes with either detection or interpretation, the bath should be drained and a new suspension made.

20.7 *Bath Characteristics Control:*

20.7.1 *Viscosity* — The viscosity of the suspension should not exceed 5 mm^2/s (5.0 cSt), at any temperature at which the bath may be used, when tested in accordance with Test Method D 445.

20.7.2 *Flash Point* — The flash point of wet magnetic particle light petroleum distillate suspension should be a minimum of 200°F (93°C); use Test Method D 93.

20.7.3 *Water Break Test for Conditioned Water Vehicles* — Properly conditioned water will provide proper wetting, particle dispersion, and corrosion protection. The water break test should be performed by flooding a part, similar in surface finish to those under test, with suspension, and then noting the appearance of the surface of the part after the flooding is stopped. If the film of suspension is continuous and even all over the part, sufficient wetting agent is present. If the film of suspension breaks, exposing bare surfaces of the part, and the suspension forms many separate droplets on the surface, more wetting agent is needed or the part has not been sufficiently cleaned.

20.7.4 *pH of Conditioned Water Vehicles* — The pH of the conditioned water bath should be between 6.0 and 10.5 as determined by a suitable pH meter or special pH paper.

20.8 *Verifying System Performance*

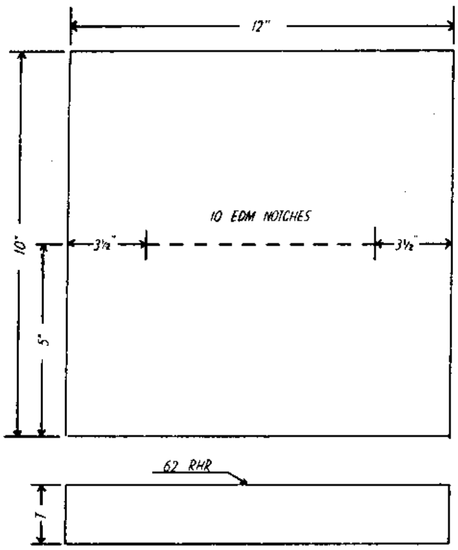
20.8.1 *Production Test Parts with Discontinuities* — A practical way to evaluate the performance and sensitivity of the dry or wet magnetic particles or overall system performance, or both, is to use representative test parts with known discontinuities of the type and severity normally encountered during actual production inspection. However, the usefulness of such parts is limited because the orientation and magnitude of the discontinuities cannot be controlled. The use of flawed parts with gross discontinuities is not recommended. **Caution** — If such parts are used, they must be thoroughly cleaned and demagnetized after each use.

20.8.2 *Fabricated Test Parts with Discontinuities* — Often, production test parts with known discontinuities of the type and severity needed for evaluation are not available. As an alternative, fabricated test specimens with discontinuities of varying degree and severity can be used to provide an indication of the effectiveness of the dry or wet magnetic particle examination process.

20.8.3 *Test Plate* — The magnetic particle system performance test plate shown in Fig. 18 is useful for testing overall performance of systems using prods and yokes.

20.8.4 *Test Ring Specimen* — The test (Ketos) ring specimen (Fig. 19) is also used in evaluating and comparing the overall performance and sensitivity of both dry and wet, fluorescent and nonfluorescent magnetic particle techniques using a central conductor magnetization technique.

20.8.4.1 *Test Ring Material* — The tool steel (Ketos) ring should be machined from AISI 01 material in accordance with Fig. 19. Either the machined ring



NOTE 1—EDM = Electronic Discharge Machine.
NOTE 2—RHR = Roughness Height Rating.
NOTE 3—Material should be the same type as material to be tested (a low-alloy steel plate is suitable for all low-alloy steel material to be tested).
NOTE 4—T should be within ±¼ in. of material to be tested up to ¾ in. T = ¾ in. for material ¾ in. and over.
NOTE 5—Ten notches are cut by the EDM process and are ⅛ in. (3 mm) long, 5 through 50 mils deep and 5 ± 1 mil wide.
NOTE 6—Notches are to be filled flush to the surface with a nonconducting material, such as epoxy, to prevent the mechanical holding of the indicating medium.

FIG. 18 MAGNETIC PARTICLE SYSTEM PERFORMANCE TEST PLATE

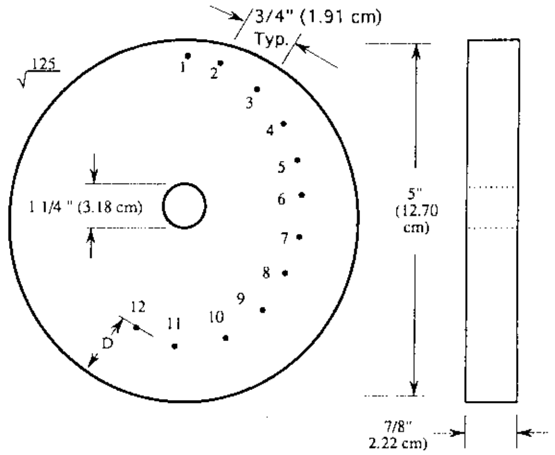
or the steel blank should be annealed at 1650°F (900°C), cooled 50°F (28°C) per hour to 1000°F (540°C) and then air cooled to ambient temperature to give comparable results using similar rings that have had the same treatment. Material and heat treatment are important variables. Experience indicates controlling the softness of the ring by hardness (90 to 95 HRB) alone is insufficient.

20.8.4.2 *Using the Test Ring* — The test ring, Fig. 19, is circularly magnetized with full-wave rectified AC passing through a central conductor with a 1 to 1¼-in. (25 to 31-mm) diameter hole located in the ring center. The conductor should have a length greater than 16 in. (400 mm). The current used, unless otherwise agreed upon by the user and the particle manufacturer, shall be 1400 amps. For dry particles the minimum number of holes shown shall be four. For wet particles the minimum number of holes shown shall be three. The ring edge should be examined after 1 min with either black light or visible light, see 20.4 depending on the type of particles involved.

20.8.5 *Magnetic Field Indicators:*

20.8.5.1 *"Pie" Field Indicator* — The magnetic field indicator shown in Fig. 15 relies on the slots between the pie shaped segments to show the presence and the approximate direction of the magnetic field. A suitable field strength is indicated when a clearly defined line of magnetic particles forms across the copper face of the indicator (the slots are against the piece) when the magnetic particles are applied simultaneously with the magnetizing force. Failure to obtain an indication can result from: (*1*) insufficient magnetic field, or (*2*) the magnetic properties of the material being examined, or both.

20.8.5.2 *Slotted Shims* — Several types of slotted shims exist. Three, shown in Fig. 16, similar but not identical, have been used by the Japanese for a number of years and are being manufactured in the United States. Slot depths of 15, 30, and 60% of the shim thickness can be obtained; the slots being chemically milled. The slotted side is placed in close contact



Hole	1	2	3	4	5	6	7	8	9	10	11	12
Diameter (Note 1)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)
"D" (Note 2)	0.07 (0.18 cm)	0.14 (0.36 cm)	0.21 (0.53 cm)	0.28 (0.71 cm)	0.35 (0.90 cm)	0.42 (1.08 cm)	0.49 (1.26 cm)	0.56 (1.44 cm)	0.63 (1.62 cm)	0.70 (1.80 cm)	0.77 (1.98 cm)	0.84 (2.16 cm)

NOTE 1—All hole diameters are ±0.005 in. (±0.01 cm). Hole numbers 8 thru 12 are optional.

NOTE 2—Tolerance on the D distance is ±0.005 in. (±0.01).

NOTE 3—All dimensions are±0.03 in. (±0.08) or as noted in 1 and 2.

NOTE 4—All dimension are in inches, except as noted.

NOTE 5—Material is ANSI 01 tool steel from annealed round stock.

NOTE 6—The ring may be heat treated as follows: Heat to 1400 to 1450°F (760 to 790°C) Hold at this temperature for one hour. Cool to a maximum rate of 40°F/h (22°C/h) to below 1000°F (540°C). Furnace or air cool to room temperature. Finish the ring to RMS 25 and protect from corrosion.

FIG. 19 TEST RING

with the piece. The linear (bar) slot is useful when discontinuities are critical in a specific direction. The circular slot indicates the direction of maximum field strength and the angular tolerance of sensitivity. It can be used for developing multidirectional magnetizing procedures. The radially slotted strip has been found most useful for parts with narrow spaces and small radii. The true continuous method (10.1.2) of magnetization must be used, that is, the particles must be applied before the current flow is stopped. For dry powder applications, the excess powder must be blown off before the current stops flowing.

20.8.6 *Half-effect Probe* — The Hall-effect probe or sensor measures the tangential field strength (in air adjacent to the part) of the magnetizing force (H) and is calibrated in gauss. The sensor must be used with care. It must be kept close to the part surface. The manufacturer's instructions should be followed. These instruments can be used to detect a residual field or measure fields produced during head shots and shots using a central conductor.

21. Procedures

21.1 When specified a procedure should be written for all magnetic particle examinations and should include as a minimum the following information. A sketch is usually used for illustrating part geometry, techniques, and areas for examination. This sketch may also be used for recording location of magnetic field indicators and for recording location of discontinuities.

21.1.1 Area to be examined (entire part or specific area),

21.1.2 Type of magnetic particle material (dry or wet, visible or fluorescent),

21.1.3 Magnetic particle equipment,

21.1.4 Part surface preparation requirements,

21.1.5 Magnetizing process (continuous, true-continuous, residual),

21.1.6 Magnetizing current (alternating, half-wave rectified AC, full-wave rectified AC, direct),

21.1.7 Means of establishing part magnetization (direct-prods, head/tailstock contact or cable wrap, indirect-coil/cable wrap, yoke, central conductor, and so forth),

21.1.8 Direction of magnetic field (circular or longitudinal),

21.1.9 System performance/sensitivity checks,

21.1.10 Magnetic field strength (ampere turns, field density, magnetizing force, and number and duration of application of magnetizing current),

21.1.11 Application of examination media,

21.1.12 Interpretation and evaluation of indications,

21.1.13 Type of records including accept/reject criteria,

21.1.14 Demagnetizing techniques, if required, and

21.1.15 Post-examination cleaning, if required,

21.2 *Written Reports* — Written reports shall be prepared as agreed upon between the testing agency/department and the purchaser/user.

22. Acceptance Standards

22.1 The acceptability of parts examined by this method is not specified herein. Acceptance standards are a matter of agreement between the manufacturer and the purchaser and should be stated in a referenced contract, specification, or code.

23. Safety

23.1 Those involved with hands-on magnetic particle examination exposure to hazards include:

23.1.1 *Electric Shock and Burns* — Electric short circuits can cause shock and particularly burns from the high amperages at relatively low voltages that are used. Equipment handling water suspensions should have good electrical grounds.

23.1.2 *Flying Particles* — Magnetic particles, particularly the dry ones, dirt, foundry sand, rust, and mill scale can enter the eyes and ears when they are blown off the part when applying them to a vertical or overhead surface or when cleaning an examined surface with compressed air. Dry particles are easy to inhale and the use of a dust respirator is recommended.

23.1.3 *Falls* — A fall from a scaffold or ladder if working on a large structure in the field or shop.

23.1.4 *Fire* — Ignition of a petroleum distillate bath.

23.1.5 *Environment* — Doing magnetic particle examination where flammable vapors are present as in a petrochemical plant or oil refinery. Underwater work has its own set of hazards.

23.1.6 *Wet Floors* — Slipping on a floor wetted with a particle suspension.

23.1.7 *Shifting or Dropping of Large Components* — Large components, especially those on temporary supports, can shift during examination or fall while being lifted. In addition, operators should be alert to the possibility of injury to body members being caught beneath a sling/chain or between head/tail stock and the piece.

23.1.8 *Ultraviolet Light Exposure* — Ultraviolet light in excess of 1000 $\mu W/cm^2$ can adversely affect the eyes and skin. Safety goggles designed to absorb UV wavelength radiation are suggested where high intensity blacklight is used.

23.1.9 *Materials and Concentrates* — The safe handling of magnetic particles and concentrates are governed by the supplier's Material Safety Data Sheets (MSDS). The MSDS conforming to 29 CFR 1910.1200 or equivalent must be provided by the supplier to any user and must be prepared in accordance with FED-STD-313.

24. Precision and Bias

24.1 The methodology described in the practice will produce repeatable results provided:

24.1.1 The strength of the magnetic flux field in the part/piece is confirmed and,

24.1.2 The field has the proper orientation with respect to the discontinuities being sought.

24.2 It must be recognized that the surface condition of the material being examined, the material's magnetic properties, its shape, and control of the factors listed in 20.1 influence the results obtained.

25. Keywords

25.1 dye; evaluation; examination; fluorescent; inspection; magnetic particle; nondestructive; testing

ANNEX
(Mandatory Information)

A1. TYPICAL MAGNETIC PARTICLE INDICATIONS

A1.1 Surface discontinuities with few exceptions produce sharp and distinct magnetic particle indications. Near-surface discontinuities on the other hand produce less distinct or fuzzy magnetic particle indications in comparison to surface discontinuities; the magnetic particle indications are broad rather than sharp and the particles are less tightly held.

A1.2 *Wet Method:*

A1.2.1 *Fluorescent* — Indications of surface cracks, surface indications, and an indication of a near surface discontinuity are shown in Figs. A1.1 through A1.6.

A1.2.2 *Nonfluorescent* — Indications of surface cracks are shown in Figs. A1.7 through A1.16.

A1.3 *Dry Method* — Indications of surface cracks are shown in Figs. A1.17 through A1.23.

A1.4 Nonrelevant indications are shown in Figs. A1.24 through A1.26.

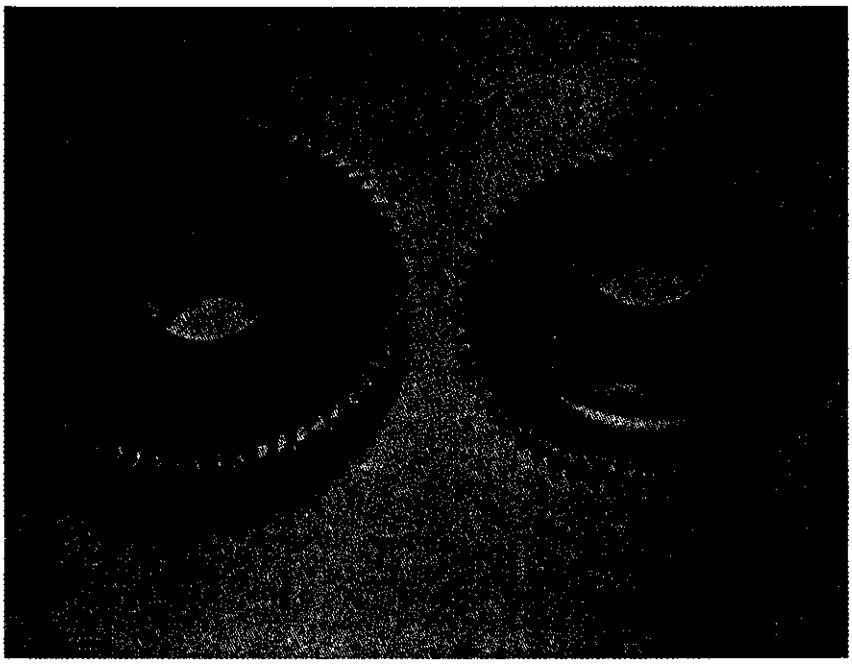


FIG. A1.1 INDICATIONS OF SURFACE CRACKS
(PRODUCED BY CENTRAL CONDUCTOR DC MAGNETIZATION)

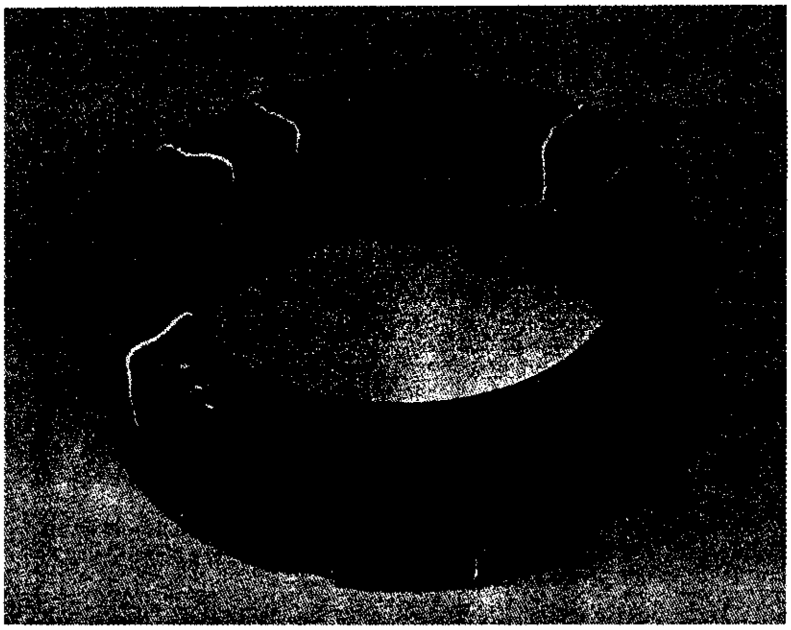


FIG. A1.2 INDICATIONS OF SURFACE CRACKS
(PRODUCED BY CENTRAL CONDUCTOR DC MAGNETIZATION)

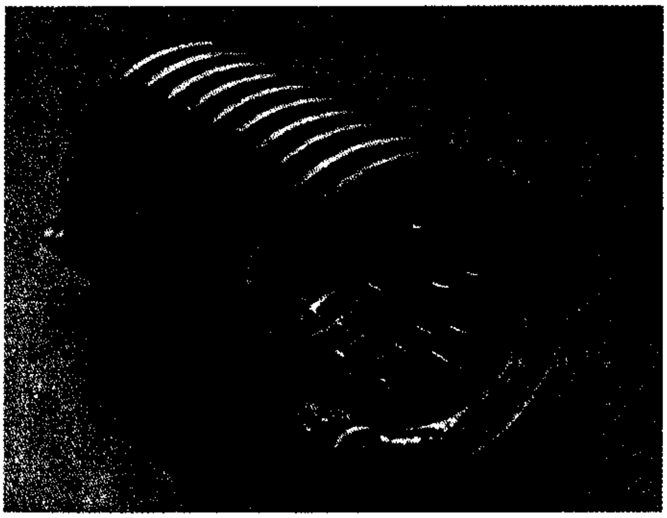


FIG. A1.3 INDICATIONS OF SURFACE CRACKS
(PRODUCED BY CENTRAL CONDUCTOR,
DC MAGNETIZATION)

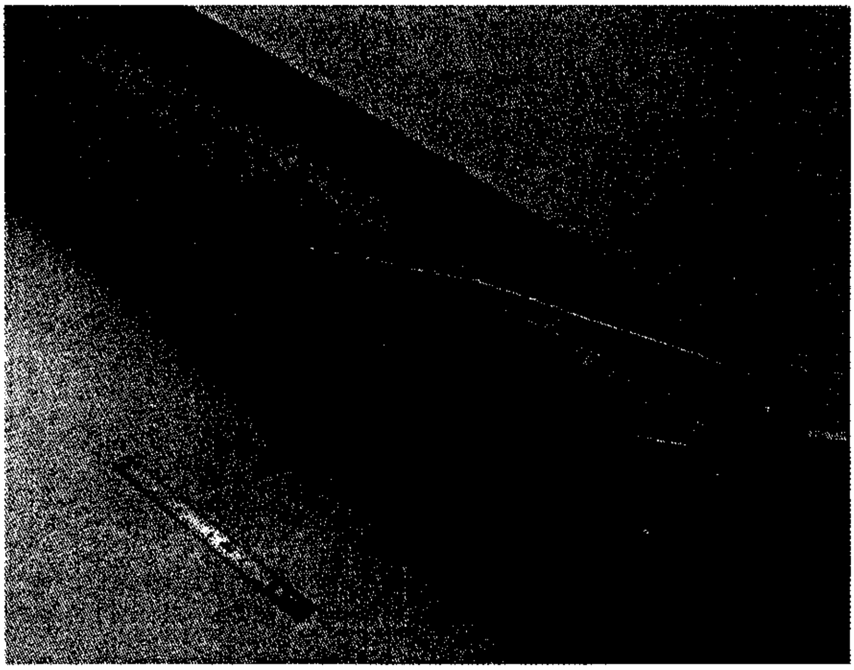


FIG. A1.4 SURFACE INDICATIONS
(PRODUCED BY CENTRAL CONDUCTOR
DC MAGNETIZATION)

FIG. A1.5 INDICATIONS OF SURFACE CRACKS
(PRODUCED BY CIRCULAR MAGNETIZATION,
DC CONTINUOUS)

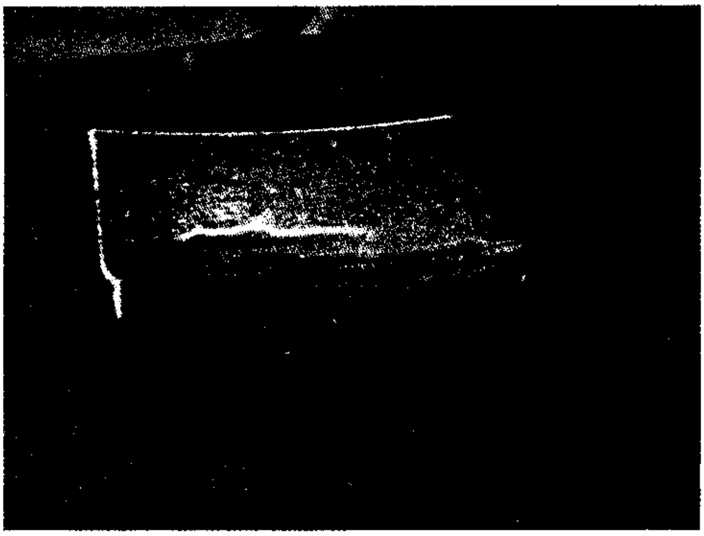


FIG. A1.6 INDICATION OF A NEAR-SURFACE DISCONTINUITY (PRODUCED BY PROD MAGNETIZATION)

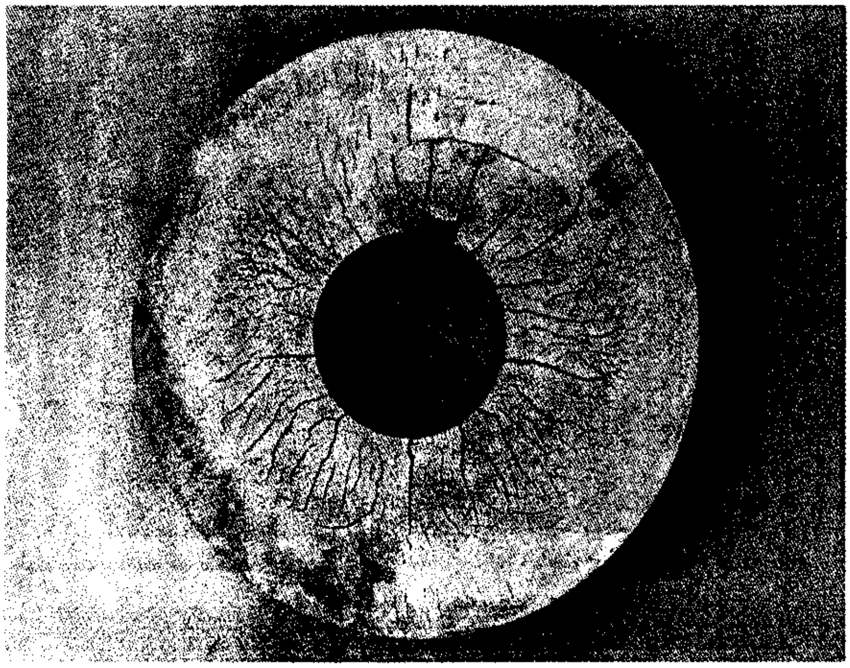


FIG. A1.7 INDICATIONS OF SURFACE CRACKING (PRODUCED BY CENTRAL CONDUCTOR MAGNETIZATION, DC CONTINUOUS)

STANDARD GUIDE FOR DETERMINING THE REPRODUCIBILITY OF ACOUSTIC EMISSION SENSOR RESPONSE

SE-976

(Identical with ASTM Specification E 976-98)

1. Scope

1.1 This guide defines simple economical procedures for testing or comparing the performance of acoustic emission sensors. These procedures allow the user to check for degradation of a sensor or to select sets of sensors with nearly identical performances. The procedures are not capable of providing an absolute calibration of the sensor nor do they assure transferability of data sets between organizations.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Significance and Use

2.1 Acoustic emission data is affected by several characteristics of the instrumentation. The most obvious of these is the system sensitivity. Of all the parameters and components contributing to the sensitivity, the acoustic emission sensor is the one most subject to variation. This variation can be a result of damage or aging, or there can be variations between nominally identical sensors. To detect such variations, it is desirable to have a method for measuring the response of a sensor to an acoustic wave. Specific purposes for checking sensors include: (1) checking the stability of its response with time; (2) checking the sensor for possible damage after accident or abuse; (3) comparing a number of sensors for use in a multichannel system to ensure that their responses are adequately matched; and (4) checking the response after thermal cycling or exposure to a hostile environment. It is very important that the sensor characteristics be always measured with the same sensor cable length and impedance as well as the same preamplifier or equivalent. This guide presents several procedures for measuring sensor response. Some of these procedures require a minimum of special equipment.

3. Principles of Application

3.1 The procedures given in this guide are designed to measure the response of an acoustic emission sensor to an arbitrary but repeatable acoustic wave. These procedures in *no* way constitute a calibration of the sensor. The absolute calibration of a sensor requires a complete knowledge of the characteristics of the acoustic wave exciting the sensor or a previously calibrated reference sensor. In either case, such a calibration is beyond the scope of this guide.

3.2 The fundamental requirement for comparing sensor responses is a source of repeatable acoustic waves. The characteristics of the wave do not need to be known as long as the wave can be reproduced at will. The sources and geometries given in this guide will produce primarily compressional waves. While the sensors will respond differently to different types of waves, changes in the response to one type of wave will imply changes in the responses to other types of waves.

3.3 These procedures all use a test block or rod. Such a device provides a convenient mounting surface for the sensor and, when appropriately marked, can ensure that the source and the sensor are always posi-

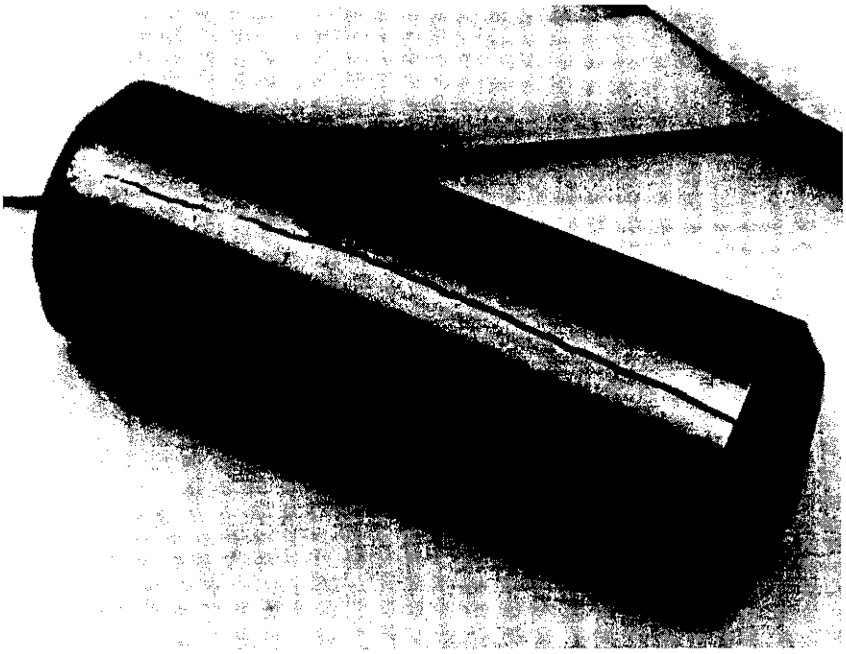


FIG. A1.10 INDICATIONS OF SURFACE CRACKS
(PRODUCED BY CIRCULAR INDIRECT MAGNETIZATION, DC)

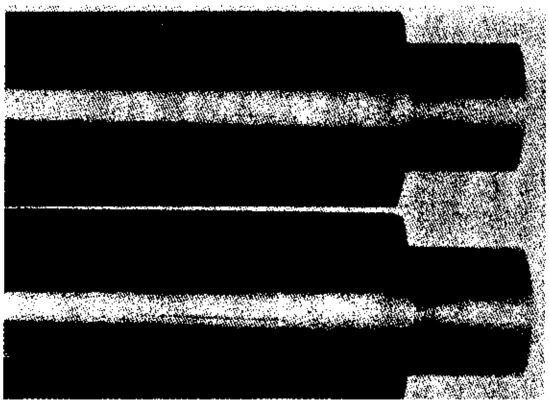


FIG. A1.11 INDICATIONS OF A NEAR-SURFACE DISCONTINUITY (PRODUCED BY CIRCULAR DIRECT MAGNETIZATION, AC CONTINUOUS)

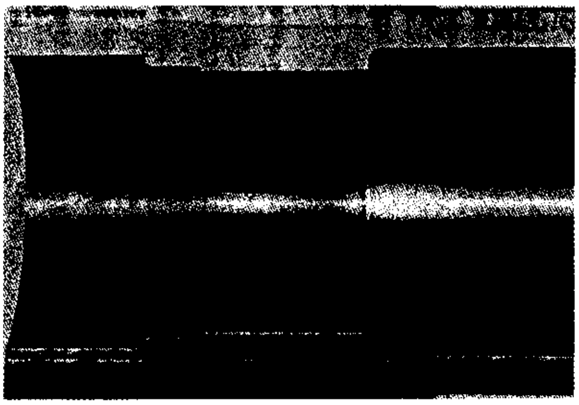


FIG. A1.12 INDICATIONS OF NEAR-SURFACE INDICATIONS (PRODUCED BY CIRCULAR DIRECT MAGNETIZATION, AC CONTINUOUS)

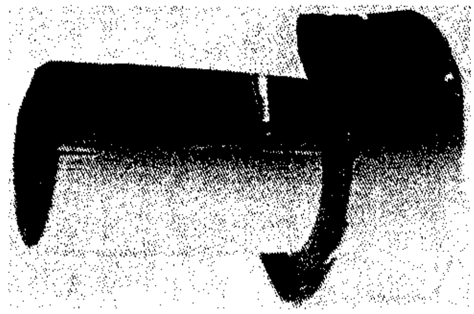


FIG. A1.13 MAGNETIC RUBBER INDICATIONS OF SURFACE CRACKS IN AIRCRAFT FASTENER HOLES (PRODUCED BY YOKE MAGNETIZATION, DC CONTINUOUS)

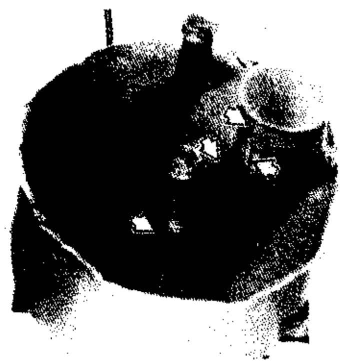


FIG. A1.14 MAGNETIC RUBBER INDICATIONS OF SURFACE CRACKS IN AIRCRAFT FASTENER HOLES (PRODUCED BY YOKE MAGNETIZATION, DC CONTINUOUS)

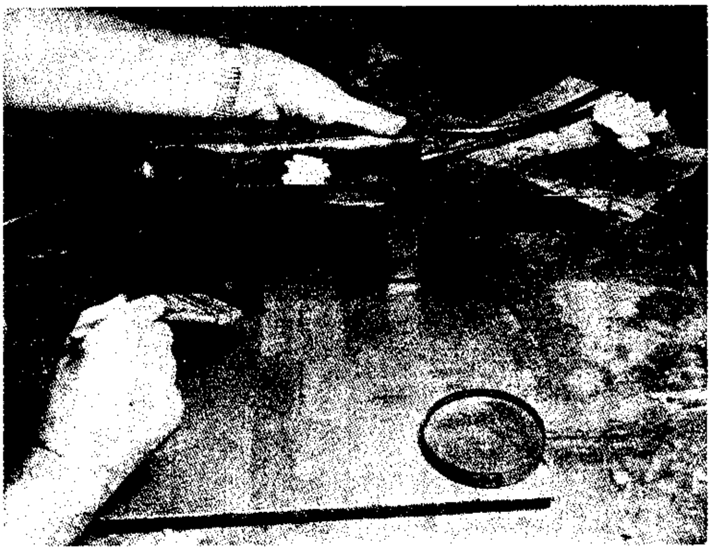


FIG. A1.15 MAGNETIC SLURRY INDICATIONS OF SURFACE CRACKS IN WELDMENT (PRODUCED BY YOKE MAGNETIZATION, AC CONTINUOUS)

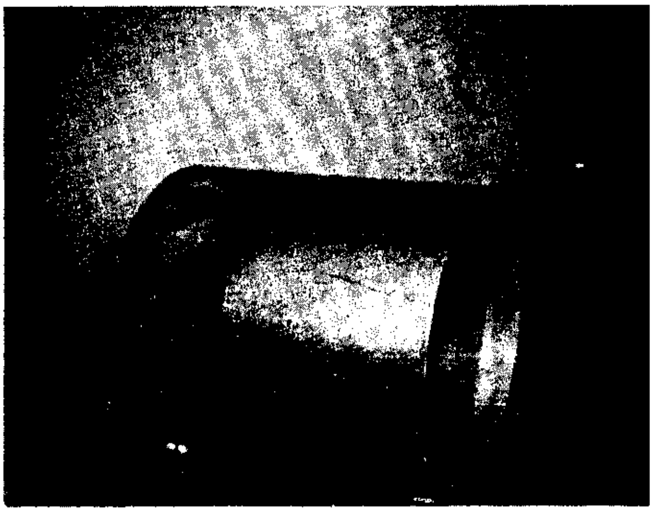


FIG. A1.16 MAGNETIC SLURRY INDICATIONS OF SURFACE CRACKS (PRODUCED BY YOKE MAGNETIZATION, AC CONTINUOUS)

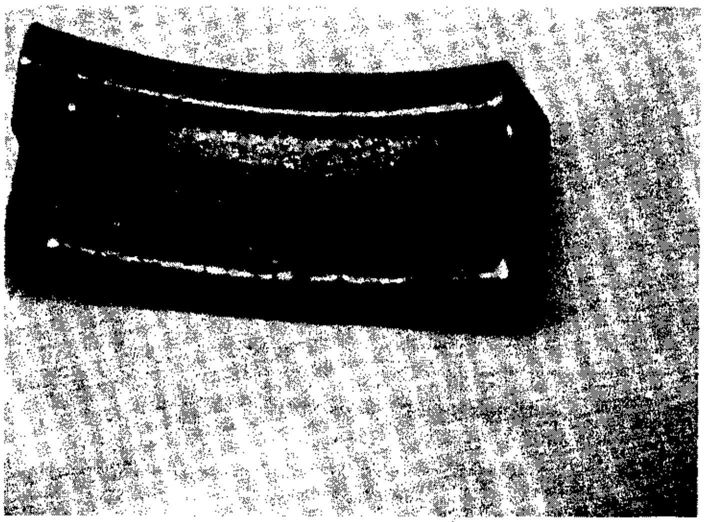


FIG. A1.17 INDICATIONS OF A NEAR-SURFACE DISCONTINUITY (PRODUCED BY PROD MAGNETIZATION, HWDC CONTINUOUS)

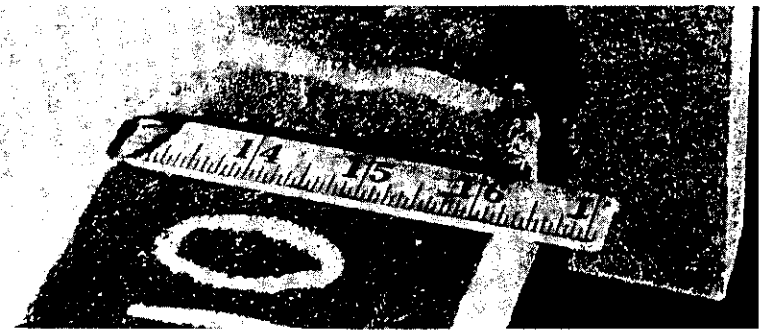


FIG. A1.18 INDICATIONS OF A NEAR-SURFACE DISCONTINUITY (PRODUCED BY PROD MAGNETIZATION, HWDC CONTINUOUS)

FIG. A1.19 INDICATION OF SURFACE CRACKS (PRODUCED BY CIRCULAR INDIRECT MAGNETIZATION, AC CONTINUOUS)

FIG. A1.20 INDICATION OF SURFACE CRACKS (PRODUCED BY PROD MAGNETIZATION, AC CONTINUOUS)

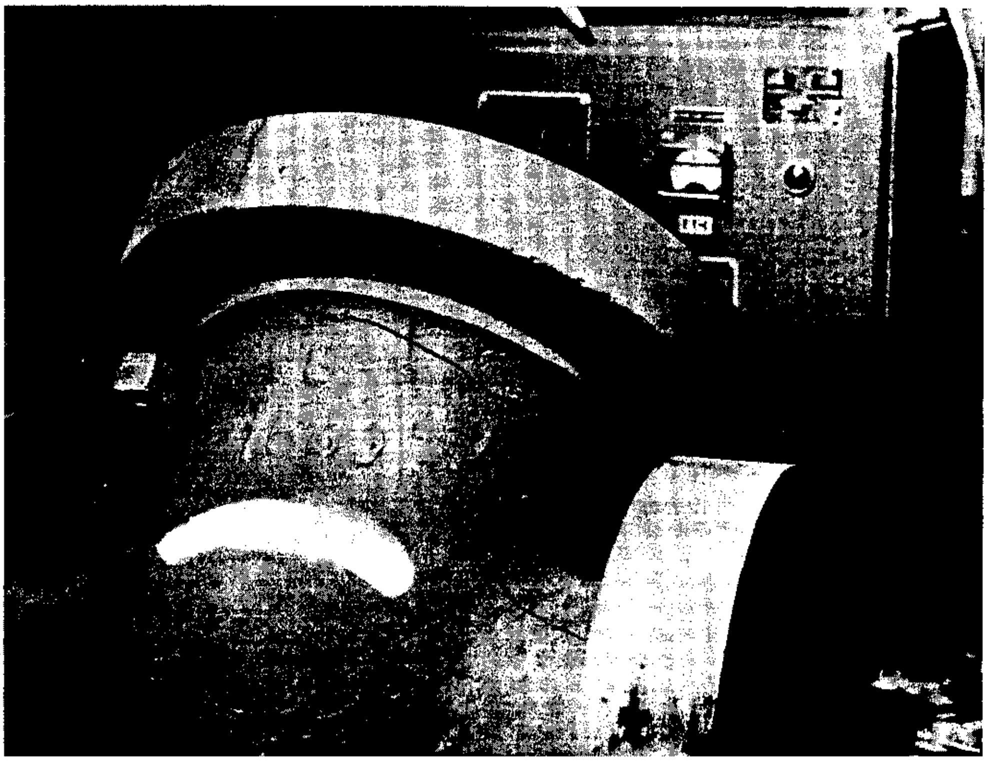


FIG. A1.21 INDICATIONS OF SURFACE CRACKS (PRODUCED BY PROD MAGNETIZATION, DC CONTINUOUS)

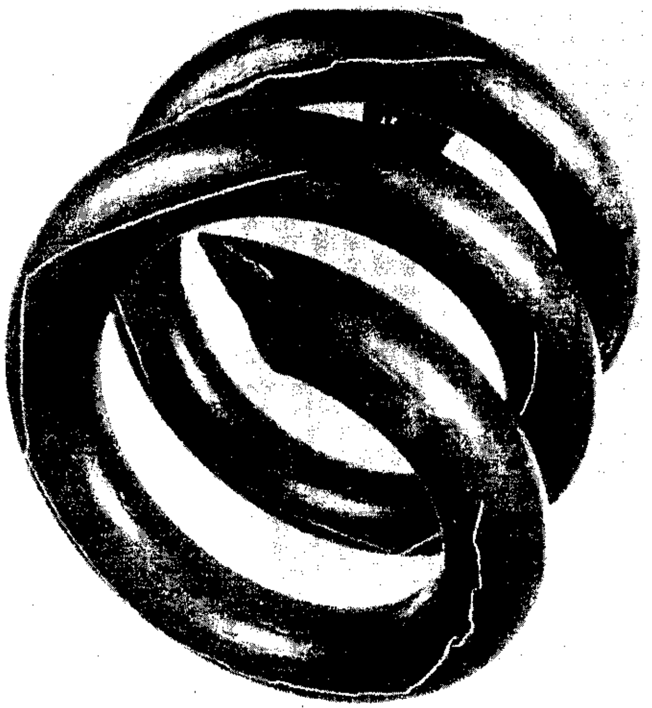


FIG. A1.22 INDICATIONS OF SURFACE CRACKS (PRODUCED BY CIRCULAR DIRECT MAGNETIZATION, AC CONTINUOUS)

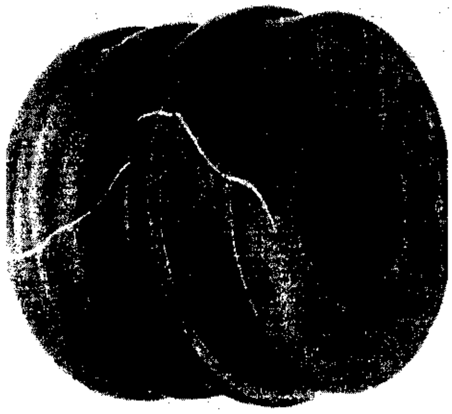


FIG. A1.23 INDICATIONS OF SURFACE CRACKS (PRODUCED BY CENTRAL CONDUCTOR MAGNETIZATION, AC CONTINUOUS)

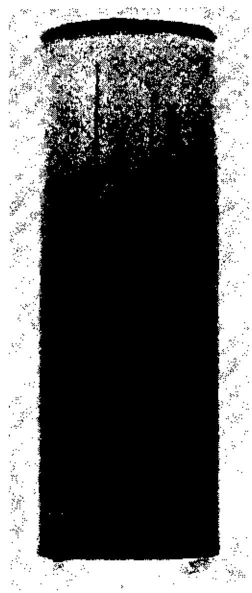


FIG. A1.24 NONRELEVANT INDICATIONS OF MAGNETIC WRITING (PRODUCED BY DIRECT MAGNETIZATION, DC CONTINUOUS)

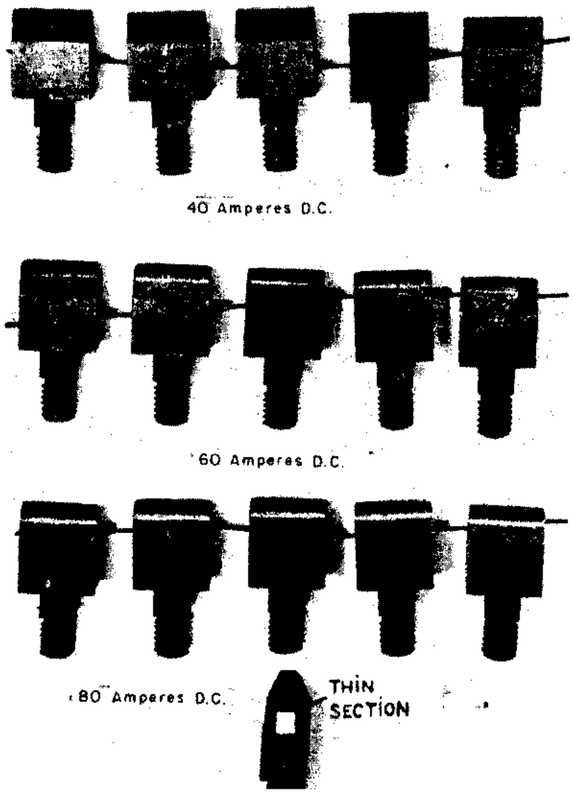


FIG. A1.25 NONRELEVANT INDICATIONS DUE TO CHANGE IN SECTION ON A SMALL PART (PRODUCED BY INDIRECT, CIRCULAR MAGNETIZATION, DC CONTINUOUS)

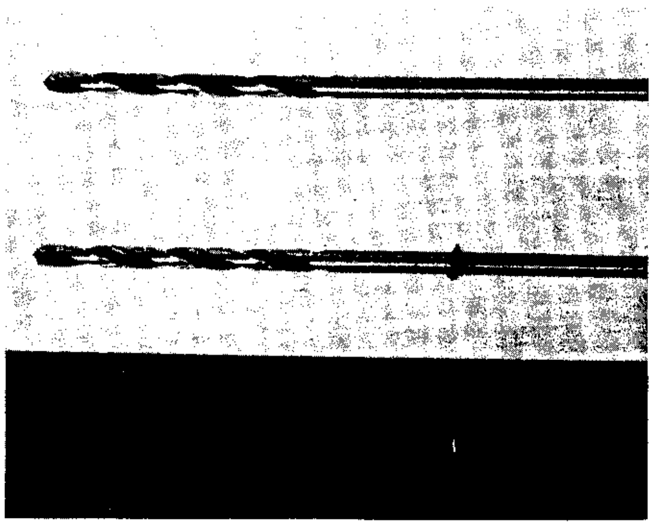


FIG. A1.26 NONRELEVANT INDICATIONS OF JUNCTION BETWEEN DISSIMILAR MATERIALS (PRODUCED BY COIL DC RESIDUAL MAGNETIZATION)

01

ARTICLE 26
EDDY CURRENT STANDARDS

RECOMMENDED PRACTICE FOR STANDARDIZING EQUIPMENT FOR ELECTROMAGNETIC TESTING OF SEAMLESS ALUMINUM-ALLOY TUBE 01

SE-215

[Identical with ASTM Specification E 215-67 (1979)[e2]]

DELETED

STANDARD PRACTICE FOR ELECTROMAGNETIC (EDDY-CURRENT) EXAMINATION OF COPPER AND COPPER-ALLOY TUBES

SE-243

(Identical with ASTM Specification E 243-97)

1. Scope

1.1 This practice covers the procedures that shall be followed in eddy-current examination of copper and copper-alloy tubes for detecting discontinuities of a severity likely to cause failure of the tube. These procedures are applicable for tubes with outside diameters to $3\frac{1}{8}$ in. (79.4 mm), inclusive, and wall thicknesses from 0.017 in. (0.432 mm) to 0.120 in. (3.04 mm), inclusive, or as otherwise stated in ASTM product specifications; or by other users of this practice. These procedures may be used for tubes beyond the size range recommended, upon contractual agreement between the purchaser and the manufacturer.

1.2 The procedures described in this practice are based on methods making use of encircling annular test coil systems.

1.3 The values stated in inch-pound units are to be regarded as the standard.

NOTE 1 — This practice may be used as a guideline for the examination, by means of internal probe test coil systems, of installations using tubular products where the outer surface of the tube is not accessible. For such applications, the technical differences associated with the use of internal probe coils should be recognized and accommodated. The effect of foreign materials on the tube surface and signals due to tube supports are typical of the factors that must be considered.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

B 111 Specification for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock
B 395 Specification for U-Bend Seamless Copper and Copper-Alloy Heat Exchanger and Condenser Tubes
B 543 Specification for Welded Copper and Copper-Alloy Heat Exchanger Tubes
E 543 Practice for Evaluating Agencies That Perform Nondestructive Testing
E 1316 Terminology for Nondestructive Examinations

2.2 *Other Documents:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification
ANSI/ASNT CP-189 ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel
MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification

3. Terminology

3.1 *Definitions of Terms Specific to this Standard*

3.1.1 The following terms are defined in relation to this standard.

3.1.1.1 *artificial discontinuity calibration standard* — a standard consisting of a selected tube with defined artificial discontinuities, used when adjusting the system controls to obtain some predetermined system output signal level. This standard may be used for periodic checking of the instrument during a test.

3.1.1.2 *percent maximum unbalance calibration standard* — a method of calibration that can be used

with speed-insensitive instruments (see 3.1.1.4). The acceptance level of the test is established at the operating test frequency as an accurately calibrated fraction of the maximum unbalance signal resulting from the end effect of a tube. Any low-noise tube from the production run having a squared end may be used as this standard. This standard may be used for periodic checking of the instrument during a test.

3.1.1.3 *electrical center* — the center established by the electromagnetic field distribution within the test coil. A constant-intensity signal, irrespective of the circumferential position of a discontinuity, is indicative of electrical centering. The electrical center may be different from the physical center of the test coil.

3.1.1.4 *speed-sensitive equipment* — test equipment that produces a variation in signal response with variations in the test speed. Speed-insensitive equipment provides a constant signal response with changing test speeds.

3.1.1.5 *off-line testing* — eddy-current tests conducted on equipment that includes the test coil and means to propel individual tubes under test through the coil at appropriate speeds and conditions.

3.1.1.6 *on-line testing* — eddy-current tests conducted on equipment that includes the test coil and means to propel tubes under test through the coil at appropriate speeds and conditions as an integral part of a continuous tube manufacturing sequence.

3.2 *Definitions of Terms* — Refer to Terminology E 1316 for definitions of terms that are applicable to nondestructive examinations in general.

4. Summary of Practice

4.1 Testing is usually performed by passing the tube lengthwise through a coil energized with alternating current at one or more frequencies. The electrical impedance of the coil is modified by the proximity of the tube, the tube dimensions, electrical conductivity and magnetic permeability of the tube material, and metallurgical or mechanical discontinuities in the tube. During passage of the tube, the changes in electromagnetic response caused by these variables in the tube produce electrical signals which are processed so as to actuate an audio or visual signaling device or mechanical marker which produces a record.

5. Significance and Use

5.1 Eddy-current testing is a nondestructive method of locating discontinuities in a product. Signals can be produced by discontinuities located either on the external or internal surface of the tube or by discontinuities totally contained within the walls. Since the density of eddy currents decreases nearly exponentially as the distance from the external surface increases, the response to deep-seated defects decreases.

5.2 Some indications obtained by this method may not be relevant to product quality; for example, a reject signal may be caused by minute dents or tool chatter marks that are not detrimental to the end use of the product. Irrelevant indications can mask unacceptable discontinuities. Relevant indications are those which result from nonacceptable discontinuities. Any indication above the reject level that is believed to be irrelevant shall be regarded as unacceptable until it is demonstrated by reexamination or other means to be irrelevant (see 10.3.2).

5.3 Eddy-current testing systems are generally not sensitive to discontinuities adjacent to the ends of the tube (end effect). On-line eddy-current testing would not be subject to end effect.

5.4 Discontinuities such as scratches or seams that are continuous and uniform for the full length of the tube may not always be detected.

6. Basis of Application

6.1 *Personnel Qualification* — Nondestructive testing (NDT) personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, MIL-STD-410, or a similar document. The practice or standard used and its applicable revision shall be specified in the purchase specification or contractual agreement between the using parties.

6.2 *Qualification of Nondestructive Testing Agencies* — If specified in the purchase specification or contractual agreement, NDT agencies shall be evaluated and qualified as described in Practice E 543. The applicable edition of Practice E 543 shall be identified in the purchase specification or contractual agreement between the using parties.

7. Apparatus

7.1 *Electronic Apparatus* — The electronic apparatus shall be capable of energizing the test coil with alternating currents of suitable frequencies (for example, 1 kHz to 125 kHz), and shall be capable of sensing the changes in the electromagnetic response of the coils. Electrical signals produced in this manner are processed so as to actuate an audio or visual signaling device or mechanical marker which produces a record.

7.2 *Test Coils* — Test coils shall be capable of inducing current in the tube and sensing changes in the electrical characteristics of the tube. The test coil diameter should be selected to yield the largest practical fill-factor.

7.3 *Driving Mechanism* — A mechanical means of passing the tube through the test coil with minimum vibration of the test coil or the tube. The device shall maintain the tube substantially concentric with the electrical center of the test coil. A uniform speed (±5.0% speed variation maximum) shall be maintained.

7.4 *End Effect Suppression Device* — A means capable of suppressing the signals produced at the ends of the tube. Individual ASTM product specifications shall specify when an end effect suppression device is mandatory.

NOTE 2 — Signals close to the ends of the tube may carry on beyond the limits of end suppression. Refer to 9.5.

8. Reference Standards

8.1 *Artificial Discontinuity Reference Standard:*

8.1.1 The tube used when adjusting the sensitivity setting of the apparatus shall be selected from a typical production run and shall be representative of the purchaser's order. The tubes shall be passed through the test coil with the instrument sensitivity high enough to determine the nominal background noise inherent in the tubes. The reference standard shall be selected from tubes exhibiting low background noise. For on-line eddy-current testing, the reference standard is created in a tube portion existent in the continuous manufacturing sequence or in other forms as allowed by the product specification.

8.1.2 The artificial discontinuities shall be spaced to provide signal resolution adequate for interpretation. The artificial discontinuities shall be prepared in accordance with one of the following options:

(*a*) A round bottom transverse notch on the outside of the tube in each of three successive transverse planes at 0, 120, and 240° (Fig. 1).

(*b*) A hole drilled radially through the tube wall in each of three successive transverse planes at 0, 120, and 240° (Fig. 2).

(*c*) One round bottom transverse notch on the outside of the tube at 0° and another at 180°, and one hole drilled radially through the wall at 90° and another at 270°. Only one notch or hole shall be made in each transverse plane (Fig. 3).

(*d*) Four round bottom transverse notches on the outside of the tube, all on the same element of the tube (Fig. 4).

(*e*) Four holes drilled radially through the tube wall, all the same element of the tube (Fig. 5).

8.1.2.1 *Round Bottom Transverse Notch* — The notch shall be made using a suitable jig with a 0.250-in. (6.35-mm) diameter No. 4 cut, straight, round file. The outside surface of the tube shall be stroked in a substantially straight line perpendicular to the axis of the tube. The notch depth shall be in accordance with the ASTM product specification or Appendix X1 if the product specification does not specify and shall not vary from the notch depth by more than ±0.0005 in. (±0.013 mm) when measured at the center of the notch (see Table X1.1).

NOTE 3 — Tables X1.1 and X1.2 should not be used for acceptance or rejection of materials.

8.1.2.2 *Drilled Holes* — The hole shall be drilled radially through the wall using a suitable drill jig that has a bushing to guide the drill, care being taken to avoid distortion of the tube while drilling. The drilled hole diameter shall be in accordance with the ASTM product specification or Appendix X1 if the product specification does not specify and shall not vary by more than +0.001, −0.000 in. (+0.026 mm) of the hole diameter specified (see Table X1.2) (Note 3).

8.1.2.3 *Other Artificial Discontinuities* — Discontinuities of other contours may be used in the reference standard by mutual agreement between supplier and purchaser.

8.2 *Percent Maximum Unbalance Reference Standard* — This method of standardization shall be used only with speed-insensitive equipment, and equipment specifically designed or adapted to accommodate the use of this calibration method. Maximum unbalance of differential coils is obtained by placing the squared end of a tube in only one of the differential coils and

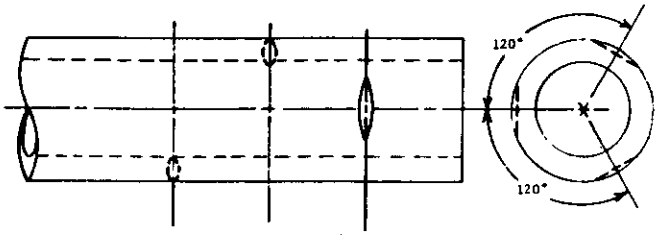


FIG. 1 REFERENCE STANDARD WITH THREE NOTCHES

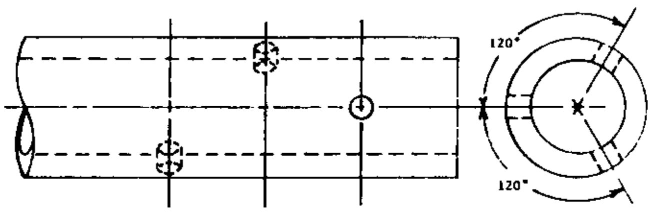
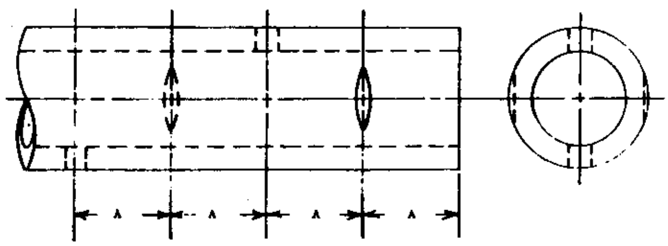
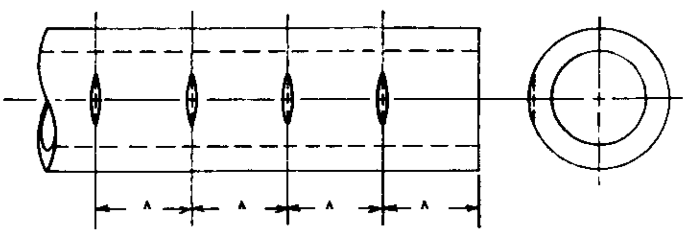


FIG. 2 REFERENCE STANDARD WITH THREE HOLES



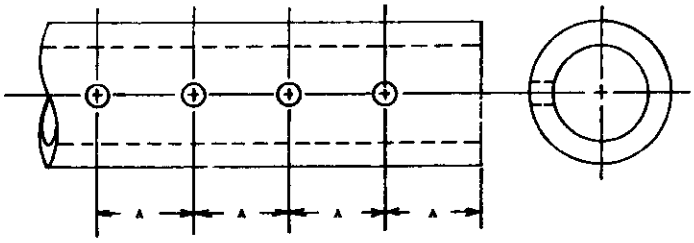
NOTE: A—Space to provide signal resolution adequate for interpretation.

FIG. 3 REFERENCE STANDARD WITH TWO NOTCHES AND TWO HOLES



NOTE: A—Space to provide signal resolution adequate for interpretation.

FIG. 4 REFERENCE STANDARD WITH FOUR NOTCHES IN LINE



NOTE: A—Space to provide signal resolution adequate for interpretation.

FIG. 5 REFERENCE STANDARD WITH FOUR HOLES IN LINE

using an accurately calibrated attenuator to obtain the (100%) maximum unbalance signal. A percentage of the maximum unbalance signal shall define the test acceptance level at a specific operating frequency and this percentage shall be obtained from the ASTM product specification.

8.3 *Other Reference Standards* — Other reference standards may be used by mutual agreement between supplier and purchaser.

NOTE 4 — Artificial discontinuities and the percent of maximum unbalance are not intended to be representative of natural discontinuities or produce a direct relationship between instrument response and discontinuity severity; they are intended only for establishing sensitivity levels as outlined in Section 9. The relationship between instrument response and discontinuity size, shape, and location is important and should be established separately, particularly as related to test frequency.

9. Adjustment and Standardization of Apparatus Sensitivity

9.1 The tube manufacturer shall select equipment, reference standard, and test parameters consistent for the product, unless otherwise agreed upon between manufacturer and purchaser.

9.2 When using the artificial discontinuity reference standard, prepared in accordance with one of the five options, adjust the apparatus to the lowest sensitivity required to detect the following:

9.2.1 For Figs. 1, 2, and 3: all artificial discontinuities in the standard. The tube speed maintained during standardization shall be the same as the speed used in production testing.

9.2.2 For Figs. 4 and 5: a minimum of two of the four artificial discontinuities as the tube is rotated by 120° intervals through 0, 120, and 240°, or by 90° intervals through 0, 90, 180, and 270° on successive passes. The tube speed maintained during standardization shall be the same as the speed used in production testing.

9.3 When using the percent maximum unbalance reference standard, adjust the apparatus to the percent unbalance called for in the ASTM product specification.

NOTE 5 — Sensitivity control settings are usually indicated by arbitrary numbers on the control panel of the testing instruments. These numerical settings differ among instruments of different types. It is, therefore, not proper to transfer numerical settings on one instrument to those of another instrument, unless the percent maximum unbalance reference standard is used. Even among instruments of the same design and from the same manufacturer, sensitivity control settings may vary. Undue emphasis on the numerical value of sensitivity control settings is not justified and shall not be used unless referenced accurately to the maximum unbalance signal.

9.4 Discard and replace the tube used as the reference standard when erroneous signals are produced from mechanical, metallurgical, or other damage to the standard.

9.5 Determine the length of tubing requiring suppression of end effect signals by selecting a tube of low background noise and making a series of reference holes or notches at 0.5-in. (12.7-mm) intervals near the end of this special tube. Pass the tube through the test coil at the production test speed with the artificial discontinuities end first, and then with the artificial discontinuities end last. Determine the distance from the tube end at which the signal response from successive discontinuities is uniform with a recording device such as a pen recorder or memory oscilloscope. Use a signal suppression method (photo relay, mechanical switches, or proximity devices are commonly used) to permit testing only when the length of tubing exhibiting uniform signals is within the test coil. The section of tube passing through the test coil during end effect suppression is not tested in accordance with 9.2 or 9.3.

9.5.1 As an option to 9.5, when a recording device is not available, the length of tubing requiring end suppression may be determined by selecting a tube of

low background noise and making a reference hole or notch at 6 to 8 in. (152 to 203 mm) from the tube end. Pass the tube through the test coil at the production test speed with the artificial discontinuity end first and then with the artificial discontinuity end last. If the artificial discontinuity is not detected, another artificial discontinuity should be made further from the end. If it is detected, cut off 0.5-in. (12.7-mm) increments from the end of the tube until the artificial discontinuity is no longer detected. The shortest distance from the end that the artificial discontinuity can be detected is that length of tube which shall require end effect signal suppression.

10. Procedure

10.1 Electrically center the tubing in the test coil at the start of the test run. The tube manufacturer may use the artificial discontinuity reference standard or prepare a separate tube for this purpose in accordance with 8.1 and 8.2. Pass the tube through the test system and mechanically adjust its position in the test coil such that the requirements of 9.2 are satisfied.

10.2 Standardize the test system at the start of the test run and at periodic intervals (for example, every 2 h) of continuous operation or whenever improper functioning of the system is suspected.

10.3 Pass the tubes through the test system standardized as described in Section 9.

10.3.1 Accept those tubes that produce output signals conforming to the limits in the applicable ASTM product specification.

10.3.2 Tubes that produce output signals not conforming to the limits in the applicable ASTM product specification may, at the option of the manufacturer, be set aside for reexamination (see 5.2). Upon reexamination, accept the tubes if the output signals are within acceptable limits (10.3.1) or demonstrated by other reexamination to be irrelevant.

10.4 Tubes may be examined at the finish size after the final anneal or heat treatment, or at the finish size prior to the final anneal or heat treatment unless otherwise agreed upon between the supplier and the purchaser.

11. Keywords

11.1 electromagnetic (eddy-current) testing; NDT; nondestructive testing; copper; tubing

APPENDIX

(Nonmandatory Information)

X1. TABLES

TABLE X1.1
NOTCH DEPTH

Tube Wall Thickness, in.	Tube Outside Diameter, in. Over $\frac{1}{4}$ to $\frac{3}{4}$, incl	Over $\frac{3}{4}$ to $1\frac{1}{4}$, incl	Over $1\frac{1}{4}$ to $3\frac{1}{8}$, incl	Tube Wall Thickness, mm	Tube Outside Diameter, mm Over 6 to 19, incl	Over 19 to 32, incl	Over 32 to 79, incl
Over 0.017–0.032	0.005	0.006	0.007	Over 0.43–0.61	0.13	0.15	0.18
Incl 0.032–0.049	0.006	0.006	0.0075	Incl 0.81–1.3	0.15	0.15	0.19
Incl 0.049–0.083	0.007	0.0075	0.008	Incl 1.3–2.1	0.18	0.19	0.20
Incl 0.083–0.109	0.0075	0.0085	0.0095	Incl 2.1–2.8	0.19	0.22	0.24
Incl 0.109–0.120	0.009	0.009	0.011	Incl 2.8–3.0	0.23	0.23	0.28

TABLE X1.2
DIAMETER OF DRILLED HOLES

Tube Outside Diameter		Diameter of Drilled Holes		
in.	mm	in.	mm	Drill No.
$\frac{1}{4}$ to $\frac{3}{4}$, incl	6.0 to 19.0, incl	0.025	0.635	72
Over $\frac{3}{4}$ to 1, incl	Over 19.0 to 25, incl	0.031	0.785	68
Over 1 to $1\frac{1}{4}$, incl	Over 25 to 32, incl	0.036	0.915	64
Over $1\frac{1}{4}$ to $1\frac{1}{2}$, incl	Over 32 to 38, incl	0.042	1.07	58
Over $1\frac{1}{2}$ to $1\frac{3}{4}$, incl	Over 38 to 45, incl	0.046	1.17	56
Over $1\frac{3}{4}$ to 2, incl	Over 45 to 50, incl	0.052	1.32	55

STANDARD PRACTICE FOR EXAMINATION OF STEEL TUBULAR PRODUCTS USING MAGNETIC SATURATION 01

SE-309

(Identical with ASTM Specification E 309-83)

DELETED

01 # STANDARD PRACTICE FOR ELECTROMAGNETIC (EDDY-CURRENT) EXAMINATION OF SEAMLESS AND WELDED TUBULAR PRODUCTS, AUSTENITIC STAINLESS STEEL, AND SIMILAR ALLOYS

SE-426

(Identical with ASTM Specification E 426-88)

DELETED

STANDARD PRACTICE FOR ELECTROMAGNETIC (EDDY-CURRENT) EXAMINATION OF NICKEL AND NICKEL ALLOY TUBULAR PRODUCTS 01

SE-571

[Identical with ASTM Specification E 571-82 (1988)]

DELETED

ARTICLE 27
LEAK TESTING STANDARDS

STANDARD RECOMMENDED GUIDE FOR THE SELECTION OF A LEAK TESTING METHOD

SE-432

[Identical with ASTM Specification E 432-71 (1984)]
(This specification is available in SI Units only.)

1. Scope

1.1 This standard is intended as a guide for the selection of a leak testing method. Figure 1 is supplied as a simplified guide.

1.2 The type of item to be tested or the test system and the method considered for either leak measurement or location are related in the order of increasing sensitivity.

2. Selection of System

2.1 The correct choice of a leak testing method optimizes sensitivity, cost, and reliability of the test. One approach is to rank the various methods according to test system sensitivity.

2.2 The various testing methods must be individually examined to determine their suitability for the particular system being tested. Only then can the appropriate method be chosen. For example, radioactive gases are not generally employed as a tracer for leak location because of the hazards associated with their use. However, such gases are employed in leakage detection equipment when they can be safely added to, and removed from, a test chamber on a periodic basis.

2.3 It is important to distinguish between the sensitivity associated with the instrument employed to measure leakage and the sensitivity of the test system followed using the instrument. The sensitivity of the instrument influences the sensitivity that can be attained in a specific test. The range of temperatures or pressures, and the types of fluids involved, influence both the choice of instrument and the test system.

2.4 The sensitivity of various test systems differ. For example, a test utilizing a mass spectrometer leak detector normally has an ultimate sensitivity of 10^{-10} standard cm^3/s when the procedure involves the measurement of a steady-state gas leakage rate. The sensitivity of the test may be increased under special conditions to 10^{-14} standard cm^3/s by allowing an integration of the leakage to occur in a known volume before a measurement of leakage is made. In the first case, the sensitivity of the test equals the sensitivity of the instrument; whereas in the second case, the sensitivity of the test is 10^4 times greater than that of the instrument. If the test system utilizes a mass spectrometer operating in the detector-probe mode, the sensitivity of the test can be 10^2 to 10^4 smaller than that of the mass spectrometer itself.

3. Leakage Measurement

3.1 In general, leakage measurement procedures involve covering the whole of the suspected region with tracer gas, while establishing a pressure differential across the system by either pressurizing with a tracer gas or by evacuating the opposite side. The presence and concentration of tracer gas on the lower pressure side of the system are determined and then measured.

3.2 A dynamic test method can be performed in the shortest time. While static techniques increase the test sensitivity, the time for testing is also increased.

3.3 Equipment or devices that are the object of leakage measurement fall into two categories: (*1*) open units, which are accessible on both sides, and (*2*) units that are sealed. The second category is usually applied to mass-produced items including gas and vacuum

tubes, transistors, integrated circuit modules, relays, ordnance units, and hermetically sealed instruments.

3.3.1 *Open or Single-Sealed Units*—Either evacuation or pressurization of one side of a unit that is accessible on both sides, may be employed to test for leakage across a unit.

3.3.1.1 *Systems Leaking to Vacuum*—In the order of increasing sensitivity for testing an evacuated system, the methods include: flow measurement, absolute pressure measurement, the alkaline-ion diode halogen detector, and the helium mass spectrometer leak detector.

The first approach to the testing of units that may be evacuated is to determine if there is an inherent tracer in the system. This gas should be utilized if possible.

When one side is evacuated, leakage of the tracer into the vacuum will reach the detector quickly if there is essentially no stratification. However, evacuation does not always allow the most sensitive and reliable measurement. If the evacuated region is extremely large, high pumping speeds will be required and the leakage gas will tend to follow streamlines to the pump port. The amount of tracer gas that reaches the detector may then be substantially reduced depending on the location of the detector in the evacuated region.

When no inherent tracer is available, the next approach should be to determine if there is a gage in the system that might be used for leakage measurement. This gage might be an ionization gage or, in some fortunate circumstances, a mass spectrometer in the system as part of the analytical instrumentation. Consideration should be given not only to gages that are normally used for leak detection, but to any gas concentration detection equipment that may be used for leakage measurement if it happens to be available. Equipment not originally intended for pressure measurement may be used; for example, it is possible to detect the pressure rise in a leaking vacuum tube by operating the grid at a positive and an anode at a negative potential, and noting an increase in anode current with time.

When there is no inherent tracer or gage within the system, a standard testing method must be chosen based on the sensitivity desired.

3.3.1.2 *Systems Leaking to Atmosphere*—The choice of a testing method for systems leaking to atmospheric pressure should be made in the same manner as suggested for evacuated systems. In the absence of an inherent tracer or a gage, one of the standard methods of making leakage measurements against atmospheric pressure must be chosen. These are, in the order of increasing sensitivity: flow measurement, pressure measurement, bubble testing (immersion), helium mass spectrometer, infrared analyzer, alkaline-ion diode halogen detector, and radioactive tracer. (Note that the helium mass spectrometer method may not be the most sensitive in this situation where the measurement is to be made at atmospheric pressure.)

3.3.2 *Multiple-Sealed Units*—In the testing of sealed units, applicable testing methods are, in the order of increasing sensitivity: bubble testing, flow measurement, pressure measurement, infrared analyzer, alkaline-ion diode halogen detector, helium mass spectrometer, and radioactive tracer. The last four methods are applicable to a back pressurizing testing procedure.

Back pressuring, or bombing, is the usual procedure used for applying a tracer gas. If the leak in the unit is exceptionally large, any tracer gas in the unit will escape rapidly when it is subjected to reduced pressure. Consequently, high-sensitivity tests for this tracer will be ineffective if the tracer gas has already escaped from the system. It is therefore recommended that all parts be tested for large leaks *after* the high sensitivity tests have been conducted. Tests for large leaks involved relatively insensitive procedures. If liquids are employed, the smaller leaks can easily become clogged and may not be detected during a subsequent high sensitivity test.

3.3.2.1 *Evacuated Unit Testing*—With evacuated units, the choice of a testing procedure is relatively simple. If the system includes a gage, this gage may be used to show the presence of gas contamination. The back pressurizing procedure should be used in the absence of an internal gage. The units should be passed through a bubble test after the back pressurizing test to locate the exceptionally large leaks. If the unit can be opened to the atmosphere, a flow measurement procedure may be used.

3.3.2.2 *Units Sealed with Air*—Testing procedures for units sealed with air may be divided into two categories: low sensitivity testing by either bubble testing, flow measurement, or pressure measurement, and high sensitivity testing using the back pressurizing technique.

3.3.2.3 *Units Sealed With Tracer Gas*—Units sealed with tracer gas may be tested for leakage of the gas out of the unit by dynamic or static procedures. Generally, the partial pressure of tracer gas inside a unit will be higher than it would be if the tracer gas were forced into an evacuated unit through a small leak as is done in the back pressurizing procedure. Thus, pre-sealing with tracer gas leads to a more

sensitive procedure involving fewer steps. As in the case with the other methods, a final inspection must be conducted by means of a bubble test procedure to locate exceptionally large leaks.

4. Leak Location

4.1 Leak location can be subdivided into a tracer probe mode and a detector probe mode. The tracer probe procedure is used when the system is evacuated, and the tracer gas comes from a probe located outside the system. The detector probe mode is used when the system is pressurized with tracer gas and testing is done at atmospheric pressure. Usually the tracer probe technique is more rapid because the gas reaches the detector at a higher concentration, despite any streaming effects, than it does with a detector probe which detects tracer gas which is highly diluted by atmospheric gases. In the detector probe mode, a higher pressure differential across the system may be used, and therefore leaks of a smaller conductance can be found. In using either mode it is important that leak location be attempted only after the presence of a leak has been verified.

4.1.1 *Testing of Evacuated Systems* (*Tracer Probe Mode*)—In the location of leaks in evacuated systems, first determine if there is an inherent detector within the system. This may be a pressure gage; preferably a gage that is specific for some tracer gas which may be used. If such a gage does not exist, the methods to use in the order of increasing sensitivity are: sonic, pressure change, gage response, high-voltage discharge, alkali-ion diode leak halogen detector, infrared detector, and mass spectrometer.

4.1.2 *Testing at Atmospheric Pressure* (*Detector Probe Mode*)—In testing a system that is leaking into atmosphere, the first consideration is whether or not the leaking fluid may be used as a tracer. This will always be the case when using either the sonic method or the bubble-testing method. However, the tracer might be of a composition that will also prove satisfactory for use with the other testing methods. In order of increasing sensitivity these methods for leak location are: chemical testing, gage response, infrared gas analyzer, mass spectrometer, and alkali-ion diode halogen detector.

4.1.2.1 When using liquid penetrants, the pressure may be atmospheric both inside and outside. Both surfaces must be accessible. Leaks are detected visually by fluorescence or coloration.

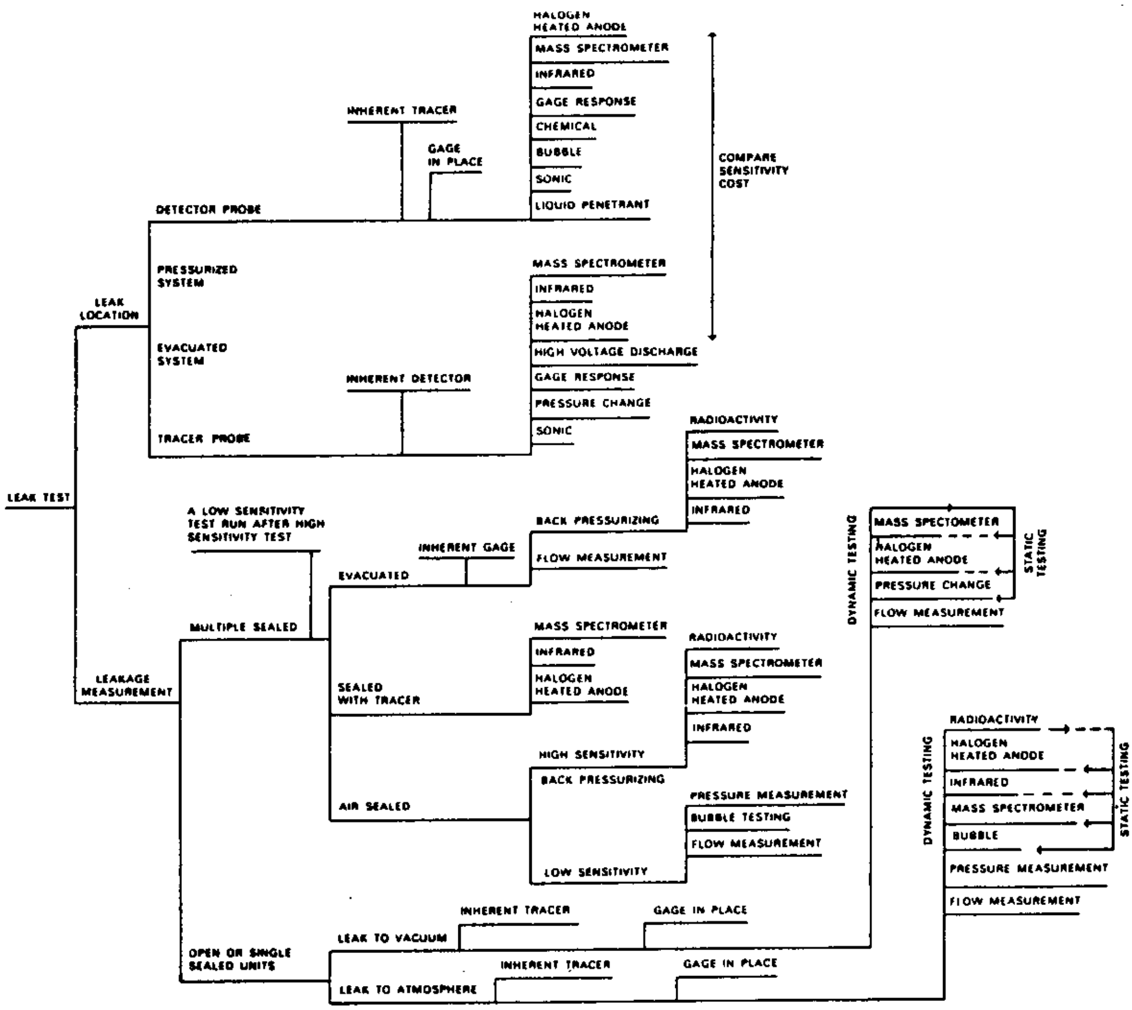


FIG. 1 GUIDE FOR SELECTION OF LEAKAGE TESTING METHOD

STANDARD GUIDE FOR PREPARATION OF A LEAK TESTING SPECIFICATION

SE-479

[Identical with ASTM Specification E 479-91 (1996)]

1. Scope

1.1 This standard is intended as a guide. It enumerates factors to be considered in preparing a definitive specification for maximum permissible gas leakage of a component, device, or system. The guide relates and provides examples of data for the preparation of leak testing specifications. It is primarily applicable for use in specifying halogen leak testing methods.

1.2 Two types of specifications are described:

1.2.1 Operational specifications (OS), and

1.2.2 Testing specifications (TS):

1.2.2.1 Total, and

1.2.2.2 Each leak.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 425 Terminology Relating to Leak Testing

E 427 Practice for Testing for Leaks Using the Halogen Leak Detector (Alkali-Ion Diode)

E 432 Guide for Selection of a Leak Testing Method

3. Terminology

3.1 *Definitions:*

3.1.1 *operational specification* (*OS*) — a specification from which the others are derived. The specification specifies and states the limits of the leakage rate of the fluid to be used for the product using criteria such as failure to operate, safety, or appearance.

3.1.2 *testing specification* (*TS*) — a specification for the detection, location, or measurement, or a combination thereof, of leakage. The operational fluid usually is not detectable with commercially available leak detectors. The leak test must be performed with a suitable test gas containing a tracer to which the detector is sensitive. The pressure magnitude and pressure direction may vary greatly from operational conditions. These and other factors are to be considered and evaluated when the leak testing performed to the requirements of the TS is to result in a product that meets most of the OS requirements. In addition, should a product be tested with a detector or tracer probe from point to point, allowance should be made for the possibility of two or more leaks, each causing less leakage than the total leakage maximum, but adding up to an amount greater than allowed.

4. Specification Content and Units

4.1 The content and units of the specification should relate the following data:

4.1.1 Mass flow per unit of time, preferably in moles per second (mol/s).

4.1.2 The pressure differential across the two sides of possible leaks, and the direction, in pounds per square inch (psi) or moles (mol).

4.1.3 Any special restrictions or statement of facts that might prohibit the use of a particular type of leak testing method.

4.1.4 The methods of the leakage specification shall not be limited to any one particular method unless it is the only one suitable. Specific leak testing methods can be selected when careful consideration of the facts is outlined (refer to Guide E 432 or the other applicable documents of Section 2).

5. Significance and Use

5.1 For any product to be tested the geometrical complexity will vary widely. However, the basic concept of determining an operative leakage specification regardless of geometries is much the same for all, whether it be simple, ordinary, or complex.

5.2 The data required for writing the OS, which is total leakage (moles), time (s), and pressure difference across the leak, are either available or can be determined by tests or measurements.

5.3 A user who selects values to be used in a leakage specification as a result of someone else having used the value or simply because of prestige reasons, may find the value or values unsatisfactory for the product.

5.4 A specification that is too restrictive may result in excessive leak testing costs. A specification that is not restrictive enough may result in premature product failure, or increased warranty costs, or both.

5.5 A typical illustration for determining a leakage specification, using the complex geometry of a refrigerant system for an example, will be used throughout this recommended guide. It is well to point out that the user should realize that the values and test methods selected do not necessarily represent the best or typical ones for this application.

6. Procedure

6.1 The example that follows is to be construed as applicable to the equipment and testing method cited, and is not to be construed as setting up mandatory leakage rates for any other equipment or method of testing. The example used to illustrate the use of this guide is as follows: An automotive air-conditioning system using Refrigerant-12 (R-12, dichlorodifluoromethane) and consisting of a compressor, condensing coil, thermostatic expansion valve, evaporating coil, vacuum-operated hot gas bypass capacity control valve, and a sealed temperature control thermostat.

6.2 *OS, Refrigerant Circuit* — It is desirable that the rechargeable portions of the system operate three years before requiring additional refrigerant: for the sealed parts, five years. Tests show that 6 oz of the normal charge can be lost before serious operational inefficiency begins, and the neoprene connecting hoses have a basic permeation rate of 1 oz/year. Inspection of the system shows that the vacuum operator of the capacity valve and the thermostat are not directly connected to the refrigerant circuit, and can thus be considered separately.

6.2.1 *Calculations:*

Leakage to be detected = 6 oz (total loss) − 1 oz × 3 years = 3 oz

Period = 3 years

Rate = 3 oz/3 years = 1 oz/year. Rate (standard units) = 1 oz/year × 1.8 × 10^{-4} (or 0.00018 = R-12 conversion factor) = 7.308 × 10^{-9} moles/s. See 6.6.3.

Pressure — The maximum operating temperature of the system will be 77°C at which temperature the pressure of the refrigerant will be about 2.07 MPa. Pressure difference = 2.07 MPa (internal) − 0.10 MPa (atmosphere) = 1.97 MPa.

6.2.2 Therefore, the following would appear on the appropriate documents: Leakage Specification (Operational): 3.6 × 10^{-5} MPa max at 1.97 MPa pressure difference (7.308 × 10^{-9} moles/s excluding hose permeation).

6.3 *TS, Refrigerant Circuit:*

6.3.1 For a unit to be tested at the OS level, any inaccuracies in the test could cause possible unit acceptance when in fact the unit may leak in excess of the amount allowed. Most testing conditions cannot duplicate operating conditions. Should a point-by-point probing technique be used, a number of smaller leaks may allow a total leakage in excess of the value specified.

6.3.2 In addition, some portions of the system may be purchased as a completed operative component. Their potential contribution to the total system leakage must be limited. It is because of the requirements of the testing specification that these and other factors are considered, and that required leak testing at levels to ensure acceptable quality levels in the final product is made with the consideration for a lesser testing cost. Often it is necessary to divide the leakage allowance equitably among various components, taking into account the statistical probability of the largest allowable

leakage occurring in a number of a given set of components.

6.3.2.1 *Division of Leakage Allowance Among System Components* — Assume in the previous example that the compressor, condensing and evaporating coils, the expansion valve, capacity control valve, and sealed thermostat all have to be considered. Also assume that the compressor and evaporating coil will both be tested separately before assembly into the system, as each has a number of fabricated joints more prone to leakage than the condensing coil. The condensing coil, considered a continuous length of tubing, can be tested at the final system test. All components except the thermostat make up some portion of the refrigerant circuit. How then should the leakage allowance be divided among them? The usually equitable way is to make the division on the basis of the number of joints in each, considering 25 mm of seam as one "joint." A tabulation example on this basis follows:

	No. of Joints	% of Total
Compressor	36	28
Condensing coil	78	60
Expansion	7	5
Capacity control valve	9	7
Total	130	100

6.4 *Factor of Safety for Leak Testing Accuracy* — When establishing the data for the factor of safety for leak testing accuracy and when performed by various people using different equipment, facilities, or operating standards, the resulting data usually will vary tremendously. Results of a round-robin test conducted by ASTM resulted in a spread of the test data of about one decade. This value is considered valid for leak tests using procedures and equipment described in Section 2. Therefore any operational specification may apply a factor of $\frac{1}{3}$ or 0.3.

6.5 *Factor of Safety for Number of Leaks per System* — When a unit or device has a number of points that may leak, the leak test is to be performed by point-to-point probing. There is a possibility that the sum of all leaks smaller than the specification total may add up to an amount in excess of it. However, this is dependent upon the number of leak possibilities or on whether there is any distortion of the normal leak distribution curve, which covers many decades of sizes. The factor assigned here may depend upon a judgment of the probability of such an event occurring, the degree of confidence needed in the leak test, and the safety factor that can be afforded. In this example, assume that the condensing coil is of welded aluminum which has a strong tendency to have porosities that leak in the range of 4.06×10^{-10} moles/s. For this reason, the TS total will be divided by five for this item, and by three for the others, that is, a factor of 0.2 and 0.3 respectively.

6.6 *Factor of Safety for Test versus Operating Conditions:*

6.6.1 *Pressure* — As a recommendation, the leakage is assumed to be proportional to the difference of the squares of the pressures on each side of the leak. However, for this example, it is assumed that a 2.76 MPa pressure difference, high pressure internal, is needed. This would allow combining the leak test with the burst test which is fixed at 2.86 MPa, absolute internal − 0.10 MPa, absolute external = 2.76 MPa. This pressure will possibly reveal leaks that can only develop with higher stress. With the operating condition at 2.07 MPa, gage max, greater leakage can be expected at the higher test pressure. Calculate the Factor of Safety as follows:

$$\text{Factor of Safety} = (P_2^2 - P_1^2)/(P_3^2 - P_1^2)$$
$$= (2.76^2 - 0.1^2)/(2.07^2 - 0.1^2) = 1.8$$

where:
P_1 = pressure, atmospheric,
P_2 = high pressure (internal), and
P_3 = pressure, operating.

Therefore, a factor of 1.8 can be applied to the operational specification.

6.6.2 *Test Gas* — Except at high ambient temperatures, most refrigerant gases normally used in a system will liquefy before the test pressure is reached. Nonetheless, other gases or a mixture of gases will be required for leak testing. The more suitable gases, such as helium, nitrogen, air, etc., have a viscosity of about 1.9×10^{-4} P, compared to 1.2×10^{-4} for most halogenated refrigerants, compared to 1×10^{0} for water and 1×10^{2} for lubricating oils. The leakage of a fluid is inversely proportional to its viscosity. Therefore, the correction for test fluid is extremely important, particularly when liquids are involved. In this example a factor of 1.2×10^{-4} divided by 1.9×10^{-4} = 0.6 will be used.

6.6.3 *Test Specifications* — From an operational specification of 7.308×10^{-9} moles/s (excluding hoses) the testing specification for the completed system is derived (Note Appendix Table X1, Nos. 1–4). Test specification, total = $1.8 \times 10^{-5} \times 0.3$ (equipment accuracy) $\times$ 1.8 (gas pressure) $\times$ 0.6 (gas viscosity) =

$1.8 \times 10^{-5} \times 0.32 = 5.8 \times 10^{-6}$. Round the coefficient to the nearest whole number. The total for all leaks will be: "Leakage specification, testing, total: 24.36×10^{-10} moles/s max at 2.76 MPa pressure differential, pressure internal." Therefore, each leak $= 24.36 \times 10^{-10} \times 0.3$ (selected by consideration of factors outlined in 6.5) $= 7.308 \times 10^{-10}$ moles/s. Rounded, each leak will be: "Leakage specification, testing, each leak: 8.12×10^{-10} moles/s at 2.76 MPa pressure differential, pressure internal."

6.6.4 *Testing Specification, Purchased Components* — When purchased components will be subject to receiving inspection for compliance with the leakage specification supplied to the vendor, these two specifications should not be the same: otherwise, parts tested at normal accuracies by the vendor may be rejected by the customer. Therefore, a typical factor of about $\frac{1}{10}$ (0.1) should be applied to the vendor's specification.

6.6.4.1 *Expansion Valve* — This component has two leakage requirements. The part common with the refrigerant system must meet its requirements; the sealed operator assembly, a diaphragm, capillary tube, and bulb filled with R-12 gas has its own operation specification.

(1) Refrigerant System Side Specifications: Test Specification, Total — In the tabulation example in 6.3.2.1 an allowance of 5% for the expansion valve compartment was established. Applying this to the similar system specification: $7.308 \times 10^{-9} \times 0.05 = 36.54 \times 10^{-11}$ moles/s. (This allowance might be increased on a statistical basis if desired.) Thus the specification for this component can be tabulated as follows:

Maximum Leakage at 2.76 MPa Differential, Pressure Internal
(Note Appendix Table X1, Nos. 5–8)

Type of Specification	Seller	User	Maximum Leakage, moles/s
Testing, total		X	36.54×10^{-11}
Testing, total	X		36.54×10^{-12}
Testing, each leak		X	12.18×10^{-11}
Testing, each leak	X		12.18×10^{-12}

Observe that a factor of $\frac{1}{3}$ has been applied for probe testing versus total leakage testing.

(2) Operator Assembly Specifications — This is an independent system, and the operational specification must be established as before. Make the following calculations:

Maximum loss of R-12 before malfunction:	2 standard cm^3
Time limit:	5 years
Pressure (internal):	0.6 MPa

Operational specification $= 2/(5 \times 3.15 \times 10^{7}) = 5.3 \times 10^{-13}$ moles/s

Using factors previously discussed, the specifications may be tabulated as follows:

Maximum Leakage at 0.48 MPa Differential, Pressure Internal
(Note Appendix Table X1, Nos. 9–13)

Type of Specification	Seller	User	Maximum Leakage, moles/s
Operational		X	5.3×10^{-13}
Testing, total	X		16.24×10^{-14}
Testing, total		X	4.06×10^{-14}
Testing, each leak	X		12.18×10^{-14}
Testing, each leak			4.06×10^{-14}

Note that the factors used are larger than normal, as the sensitivity limit for the detection of halogen has been approached. (See Practice E 427.)

6.6.4.2 *Control Valve* — There are two separate leakages to consider for this component: the refrigerant side and the operational side. Applying appropriate factors, the specifications may be tabulated as follows:

Refrigerant Circuit Side Specifications:

Maximum Leakage at 2.76 MPa Differential, Pressure Internal
(Note Appendix Table X1, Nos. 14–17)

Type of Specification	Seller	User	Maximum Leakage, moles/s
Testing, total			8.12×10^{-10}
Testing, total	X		8.12×10^{-11}
Testing, each leak		X	24.36×10^{-11}
Testing, each leak	X		24.36×10^{-12}

Calculation, testing, total: $7.308 \times 10^{-9} \times 0.09$ (see the tabulation example in 6.3.2.1) $= 6.5 \times 10^{-10}$ moles/s.

Operator Specifications:

Maximum Leakage at 0.10 MPa Differential, Pressure External
(Note Appendix Table X1, Nos. 18–20)

Type of Specification	Seller	User	Maximum Leakage, moles/s
Testing, total		X	4.06×10^{-5}
Testing, total	X		4.06×10^{-4}

As this component is nonrepairable, and because the diaphragm is accessible only through parts on each side of its enclosure, probe testing to locate points of leakage is neither possible nor desirable.

6.6.4.3 *Thermostat* — No parts are in contact with the refrigerant circuit. The unit components usually are sealed in an inert atmosphere at one atmosphere pressure, to prevent contaminants and oxidation. It is preferred to specify the tracer gas to be used, in order to control the electrical characteristics and contact life.

As a rule, probing tests are difficult and not necessary, as defective units will be scrapped. Test data have revealed that a seal that leaks no more than 4.06×10^{-11} moles/s at 0.10 MPa differential will give adequate protection at the normally small operating differentials.

Maximum Leakage at 0.10 MPa Differential, Pressure Internal
(Note Appendix Table X1, Nos. 21–23)

Type of Specification	Seller	User	Maximum Leakage, moles/s
Operational			4.06×10^{-11}
Testing, total		X	12.18×10^{-13}[a]
Testing, total	X		12.18×10^{-14}[a]

[a] Fill to be 10% helium in dry nitrogen. This value pertains to helium leakage only.

7. Summary of Requirements

7.1 A leakage specification should contain all the requirements for the qualifying procedure. It shall specify:

7.1.1 Mass flow, preferably in mol/s,

7.1.2 Time, preferably in seconds,

7.1.3 Pressure differential, preferably in mol/s,

7.1.4 Direction of pressure differential,

7.1.5 Other restrictions only when necessary, and

7.1.6 Intended use of specifications:

7.1.6.1 Operational.

7.1.6.2 Testing, total.

7.1.6.3 Testing, each leak (optional).

7.1.6.4 Testing, total, seller (optional).

7.1.6.5 Testing, each leak, seller (optional).

APPENDIX

(Nonmandatory Information)

X1. PRELIMINARY LEAK TESTS

X1.1 It should be noted that furnished specifications in no way prevent the manufacturer or seller from making his own interim leak tests. It should be determined, however, that such tests do not prejudice the required tests. For example, a preliminary bubble test underwater might temporarily plug small leaks. As an example, consider line 11, Table X1, "Expansion valve operator assembly, seller, max leakage 1×10^{-9} standard cm^3/s at 70 psi (0.48 MPa) differential, pressure internal." The seller wishes to test the assembly before fitting and sealing. He elects to use the helium mass spectrometer with 100% helium external test gas. He computes the expected difference in leak rate:

$$\text{Factor of Safety} = (P_2^2 - P^2)/(P_4^2 - P_3^2) = (0.1^2 - 0^2)/(0.57^2 - 0.1^2) = 0.03$$

Therefore he will get a value of $1 \times 10^{-10} \times 0.03 = 12.18 \times 10^{-16}$ moles/s. However, in leaks of this size, helium leaks about 7 times faster than R-12. Therefore, he may desire to use the specification value of $3 \times 10^{-12} \times 7 = 8.12 \times 10^{-15}$ moles/s as a preliminary test.

TABLE X1
LEAKAGE SPECIFICATION DEVELOPED IN EXAMPLE, AUTOMOTIVE AIR CONDITIONER

No.	Component	Type of Specification	Seller	User	Pressure Internal	Pressure External	Differential, MPa (psi)	Max Leakage, moles/s	Methods Considered[a]
1.	Hoses	operational			X		2.07 (300)	7.308×10^{-9}	A1
2.	Refrigerant system except hoses	operational			X		2.07 (300)	7.308×10^{-9}	A1
3.	Refrigerant system except hoses	testing total		X	X		2.76 (400)	24.36×10^{-10}	A, B
4.	Refrigerant system except hoses	testing, each leak		X	X		2.76 (400)	8.12×10^{-10}	A, B
5.	Expansion valve refrigeration system	testing total		X	X		2.76 (400)	36.54×10^{-11}	A, B
6.	Expansion valve refrigeration system	testing total	X		X		2.76 (400)	36.54×10^{-12}	A, B
7.	Expansion valve refrigeration system	testing, each leak		X	X		2.76 (400)	12.18×10^{-11}	A2
8.	Expansion valve refrigeration system	testing, each leak	X		X		2.76 (400)	12.18×10^{-13}	A2
9.	Expansion valve operator assembly	operational			X		0.48 (70)	5.3×10^{-13}	A1
10.	Expansion valve operator assembly	testing total		X	X		0.48 (70)	16.24×10^{-14}	A1
11.	Expansion valve operator assembly	testing total	X		X		0.48 (70)	4.06×10^{-14}	A1
12.	Expansion valve operator assembly	testing, each leak		X	X		0.48 (70)	12.18×10^{-14}	A1
13.	Expansion valve operator assembly	testing, each leak	X		X		0.48 (70)	4.06×10^{-14}	A1
14.	Control valve refrigeration system	testing total		X	X		2.76 (400)	8.12×10^{-10}	A, B
15.	Control valve refrigeration system	testing total	X		X		2.76 (400)	8.12×10^{-11}	A, B
16.	Control valve refrigeration system	testing, each leak		X	X		2.76 (400)	24.36×10^{-11}	A2
17.	Control valve refrigeration system	testing, each leak	X		X		2.76 (400)	24.36×10^{-12}	A2
18.	Control valve operator system	operational				X	0.10 (15)	4.06×10^{1}	A
19.	Control valve operator system	testing total		X		X	0.10 (15)	4.06×10^{-5}	C3
20.	Control valve operator system	testing total	X			X	0.10 (15)	4.06×10^{-6}	C3
21.	Thermostat	operational			X		0.10 (15)	4.06×10^{-11}	B1
22.	Thermostat	testing total		X	X		0.10 (15)	12.18×10^{-13}[b]	B1
23.	Thermostat	testing total	X		X		0.10 (15)	12.18×10^{-14}[b]	B1

[a] The last column, "Methods Considered," is not a proper part of the specifications. It and the footnotes were appended to show test methods that were considered.

Methods Considered

A. Halogen, alkali-diode
B. Helium mass spectrometer, tracer internal
C. Sensitive flowmeter

Reasons for Suitability

1. Inherent tracer
2. Adequate sensitivity
3. Quantitative measurement of large leaks

[b] Fill to be 10% helium in dry nitrogen. This value is for helium leakage only.

ARTICLE 28
VISUAL EXAMINATION STANDARDS

STANDARD PRACTICE FOR CLASSIFYING VISUAL DEFECTS IN GLASS-REINFORCED PLASTIC LAMINATE PARTS

SD-2563

(Identical with ASTM Specification D 2563-94)

1. Scope

1.1 This practice covers acceptance criteria for visual inspection of parts made from glass-reinforced plastic laminates.

1.2 One objective of this recommended practice is to present word descriptions of possible defects to serve as a guide for contracts, drawings, product specifications, and final inspection.

1.3 This practice also categorizes different inspection requirements for levels of product quality.

1.4 The allowable size and frequency of permitted defects within the acceptance level categories of this specification are general and not related to specific service requirements. A Level IV of allowable defects which defines allowable size, frequency, and permitted repair procedures should be established for specific service requirements as agreed upon between the purchaser and the supplier.

1.5 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 1 — There is no known ISO equivalent to this practice.

2. Acceptance Criteria

2.1 The method and frequency of sampling and the allowable defects may be previously agreed upon between the purchaser and the seller.

2.2 *Dimensions and Tolerances* — Parts shall be inspected for conformance with dimensions and tolerances specified on the drawings. Any dimensions falling outside the specified limits shall be cause for rejection.

2.3 *Inserts* — All inserts, nuts, studs, and lugs shall not be damaged in any way, nor coated with laminate materials in such a way as to impair function or mechanical fit. Threads in molded-in inserts shall be clean, smooth, free of nicks, tears, or other damage. There shall be no laminate materials or flash on the threads. If necessary, threaded inserts may be retapped to clean them or remove flash. Threads containing locking features or coated for corrosion resistance shall not be retapped.

2.4 *Molded-In Threads or Cored Holes* — Molded-in threads or cored holes shall be free of visible defects such as chips, cracks, shorts, etc. Molded-in threads may be retapped or repaired unless otherwise specifically noted on the product drawings.

2.5 *Workmanship* — Workmanship shall be in accordance with good commercial practices as listed in Table 1 for applicable acceptance levels.

2.6 *Critical Area* — Some portions of a part may be considered more critical than others. A critical area is here defined as an area in which the presence of imperfections is considered to be most detrimental. The areas of parts that are critical structurally, aerodynamically, or electrically shall be uniform and free of defects

as listed in Table 1, if so stated on the product drawing. Critical areas may be designated on the product drawing by one of the following methods:

2.6.1 Encircle critical areas, or

2.6.2 Cross-hatch areas to designate areas of various levels, or

2.6.3 Word description.

2.7 *Allowable Defects, Visual* — The defects in noncritical areas which by nature, content, or frequency do not affect serviceability of the part are designated as allowable defects. Allowable defects shall be fully described as to type, size, number, extent allowed, and spacing. The appropriate acceptance level (Table 1) for defects in these areas must be specified. Where Level IV is used the defects must be fully described on the product drawing. Defects greater than those listed in the product specifications, drawings, or contracts for the part shall be cause for rejection.

2.8 *Repairable Defects* — Repairable defects, if any, shall consist of those which can be repaired without affecting the serviceability of the part unless prohibited in the product drawing or in the contract. Acceptable methods of repair shall be agreed upon between the purchaser and the seller and shall be only as specified in the product drawing or contracts for the part.

2.9 *Surface Finish* — The over-all surface finish of laminates may vary with the process used and the type of reinforcement. Unless surface finish is specified on part drawings, contracts, or orders from the purchaser, parts shall not be rejected for any reading less than 150 rms. Defects shall be considered as not included in overall surface finish.

2.10 *Surface Appearance* — The surface appearance or color, or both, of laminated parts can vary considerably depending on the process used to make the laminate, thickness, type of reinforcement, type of resin, resin-to-reinforcement ratio, and the presence of defects. Any questions concerning surface appearance and its influence on the properties of the part should be brought to the attention of the responsible materials engineer.

3. Acceptance Levels

3.1 *Visual Inspection* — Each part shall be checked visually without the aid of magnification. Defects shall be classified as to type and level as shown in Table 1 (see Note 2). The acceptable quality level shall be determined by reference to the part drawing for the applicable acceptance level for allowable defects. If none of the first three levels (Level I, II, III) is considered applicable, the level shall be Level IV, and allowable defects must be specified on the product drawing. Any excess of defects as specified under the required level shall be cause for rejection. Unless otherwise specified, dimensions are surface dimensions.

NOTE 2—Typical defects as outlined in the word descriptions of Table 1 are illustrated in Figs. 1 to 21.

3.2 *Acceptance Level I* — Presence of any defects in excess of those listed in Table 1, Level I, shall be cause for rejection, unless otherwise specified in Table 1, Level I.

3.3 *Acceptance Level II* — Presence of more than one defect of those listed in Table 1, Level II, for each estimated 10 in.^{2} of surface shall be cause for rejection, unless otherwise specified in Table 1, Level II. No defect area shall be less than 2 in. from another.

3.4 *Acceptance Level III* — Presence of more than two defects of those listed in Table 1, Level III, for each estimated 13 mm (5 in.)^2 of surface shall be cause for rejection, unless otherwise specified in Table 1, Level III. No defect area shall be less than 1 in. from another.

3.5 *Acceptance Level IV* — To be specified on the product drawing.

4. Keywords

4.1 reinforced thermosetting plastics; visual defects

TABLE 1
ALLOWABLE DEFECTS

Name	Definition	Visual Acceptance Levels		
		Level I	Level II	Level III
Chip	a small piece broken off an edge or surface	none	maximum dimension of break, 3.0 mm ($^1/_8$ in.)	maximum dimension of break, 6.5 mm ($^1/_4$ in.)
Crack	an actual separation of the laminate, visible on opposite surfaces, and extending through the thickness	none	none	none
Crack, surface	crack existing only on the surface of the laminate	none	maximum length, 3.0 mm ($^1/_8$ in.)	maximum length 6.5 mm ($^1/_4$ in.)
Crazing	fine cracks at or under the surface of a laminate	none	maximum dimension of crazing, 13 mm ($^1/_2$ in.)	maximum dimension of crazing, 25 mm (1 in.)
			frequency and location to be determined by customer	
Delamination, edge	separation of the layers of material at the edge of a laminate	none	maximum dimension, 3.0 mm ($^1/_8$ in.)	maximum dimension, 6.5 mm ($^1/_4$ in.)
Delamination, internal	separation of the layers of material in a laminate	none	none	none
Dry-spot	area of incomplete surface film where the reinforcement has not been wetted with resin	none	maximum diameter, 9.5 mm ($^3/_8$ in.)	maximum diameter, 14 mm ($^9/_{16}$ in.)
Foreign inclusion (metallic)	metallic particles included in a laminate which are foreign to its composition	none	none, if for electrical use; maximum dimension, 0.8 mm ($^1/_{32}$ in.), 1/0.09 m^2 (1 ft^2), if for mechanical use	none, if for electrical use; maximum dimension, 1.5 mm ($^1/_{16}$ in.), 1/0.09 m^2 (1 ft^2), if for mechanical use
Foreign inclusion (nonmetallic)	nonmetallic particles of substance included in a laminate which seem foreign to its composition	none	maximum dimension, 0.8 mm ($^1/_{32}$ in.), 1/0.09 m^2 (1 ft^2)	maximum dimension, 1.5 mm ($^1/_{16}$ in.); 1/0.09 m^2 (1 ft^2)
Fracture	rupture of laminate surface without complete penetration	none	maximum dimension, 21 mm ($^{13}/_{16}$ in.)	maximum dimension, 29 mm (1$^1/_8$ in.)
Air bubble (void)	air entrapment within and between the plies of reinforcement, usually spherical in shape	none	maximum diameter, 1.5 mm ($^1/_{16}$ in.); 2/in.^{2}	maximum diameter, 3.0 mm ($^1/_8$ in.); 4/in.^{2}
Blister	rounded elevation of the surface of a laminate, with boundaries that may be more or less sharply defined, somewhat resembling in shape a blister on the human skin	none	maximum diameter, 3.0 mm ($^1/_8$ in.); height from surface not to be outside drawing tolerance	maximum diameter, 6.5 mm ($^1/_4$ in.); height from surface not to be outside drawing tolerance
Burned	showing evidence of thermal decomposition through some discoloration, distortion, or destruction of the surface of the laminate	none	none	none
Fish-eye	small globular mass which has not blended completely into the surrounding material and is particularly evident in a transparent or translucent material	none	maximum diameter, 9.5 mm ($^3/_8$ in.)	maximum diameter, 13 mm ($^1/_2$ in.)
Lack of fillout	an area, occurring usually at the edge of a laminated plastic, where the reinforcement has not been wetted with resin	none	maximum diameter, 6.5 mm ($^1/_4$ in.)	maximum diameter, 9.5 mm ($^3/_8$ in.)

TABLE 1 (CONT'D)
ALLOWABLE DEFECTS

Name	Definition	Visual Acceptance Levels		
		Level I	Level II	Level III
Orange-peel	uneven surface somewhat resembling an orange peel	none	maximum diameter, 14 mm ($^9/_{16}$ in.)	maximum diameter, 29 mm ($1^1/_8$ in.)
Pimple	small, sharp, or conical elevation on the surface of a laminate	none	none	maximum diameter, 3.0 mm ($^1/_8$ in.)
Pit (pinhole)	small crater in the surface of a laminate, with its width approximately of the same order of magnitude as its depth	none	maximum diameter, 0.4 mm ($^1/_{64}$ in.); depth less than 1 percent of wall thickness	maximum diameter, 0.8 mm ($^1/_{32}$ in.); depth less than 20 percent of wall thickness
			frequency and location to be determined by customer	
Porosity (pinhole)	presence of numerous visible pits (pinholes)	none	maximum of 25 pits (pinholes) in porous area of size listed in Level II	maximum of 50 pits (pinholes) in porous area of size listed in Level III
Pre-gel	an unintentional extra layer of cured resin on part of the surface of the laminate (This condition does not include gel coats.)	none	maximum dimension, 6.5 mm ($^1/_4$ in.); height above surface not to be outside drawing tolerance	maximum dimension, 13 mm ($^1/_2$ in.); height above surface not to be outside drawing tolerance
Resin-pocket	an apparent accumulation of excess resin in a small localized area within the laminate	none	maximum diameter, 3.0 mm ($^1/_8$ in.)	maximum diameter, 6.5 mm ($^1/_4$ in.)
Resin-rich edge	insufficient reinforcing material at the edge of molded laminate	none	maximum, 0.4 mm ($^1/_{64}$ in.) from the edge	maximum, 0.8 mm ($^1/_{32}$ in.) from the edge
Shrink mark (sink)	depression in the surface of a molded laminate where it has retracted from the mold	none	maximum diameter, 9.5 mm ($^3/_8$ in.); depth not greater than 25 percent of wall thickness	maximum diameter, 14 mm ($^9/_{16}$ in.); depth not greater than 25 percent of wall thickness
Wash	area where the reinforcement of molded plastic has moved inadvertently during closure of the mold resulting in resin-rich areas	none	maximum dimension, 21 mm ($^{13}/_{16}$ in.)	maximum dimension, 29 mm ($1^1/_8$ in.)
Wormhole	elongated air entrapment which is either in or near the surface of a laminate and may be covered by a thin film of cured resin	none	maximum diameter, 3.0 mm ($^1/_8$ in.)	maximum diameter, 6.5 mm ($^1/_4$ in.)
Wrinkles	in a laminate, an imperfection that has the appearance of a wave molded into one or more plies of fabric or other reinforcement material	none	maximum length surface side, 13 mm ($^1/_2$ in.); maximum length opposite side, 13 mm ($^1/_2$ in.); depth less than 10 percent of wall thickness	maximum length surface side, 25 mm (1 in.); maximum length opposite side, 25 mm (1 in.); depth less than 15 percent of wall thickness
Scratch	shallow mark, groove, furrow, or channel caused by improper handling or storage	none	maximum length, 25 mm (1.0 in.); maximum depth, 0.125 (0.005 in.)	maximum length, 25 mm (1.0 in.); maximum depth, 0.255 (0.010 in.)
Short	in a laminate, an incompletely filled out condition NOTE — this may be evident either through an absence of surface film in some areas, or as lighter unfused particles of material showing through a covering surface film, possibly accompanied by thin-skinned blisters.	none	none	none

FIG. 1 CHIPS (A), SURFACE CRACKS (B), INTERPLY DELAMINATION (C)

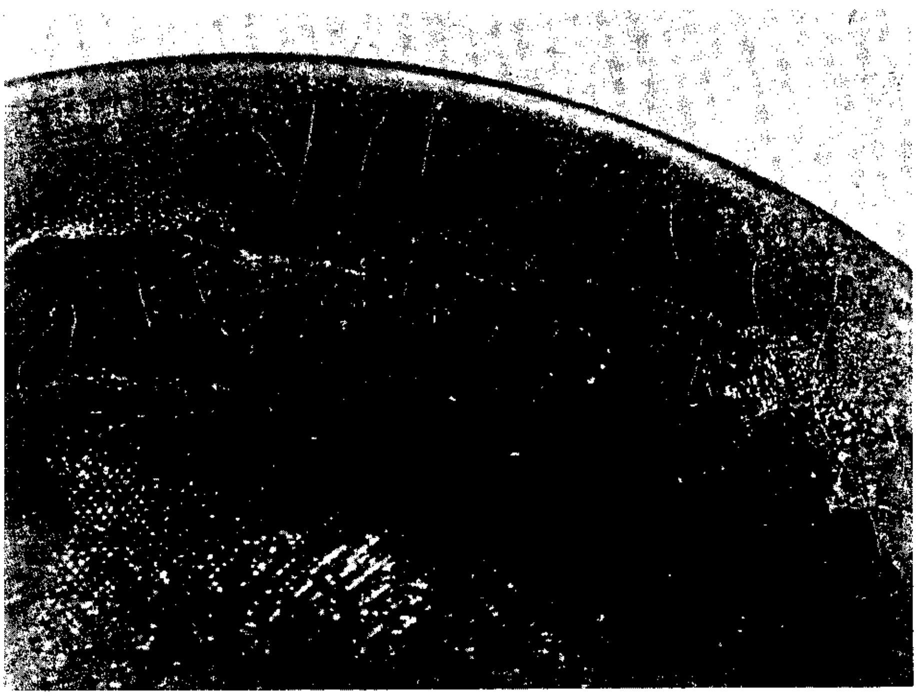


FIG. 2 CRAZING

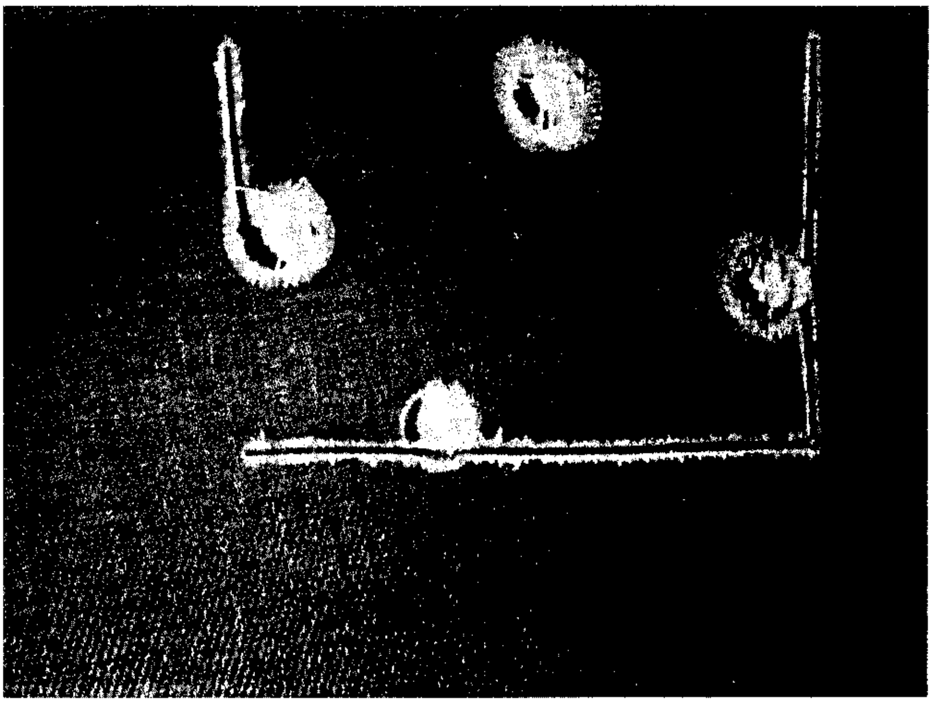


FIG. 3 DELAMINATION BY IMPROPER MACHINING

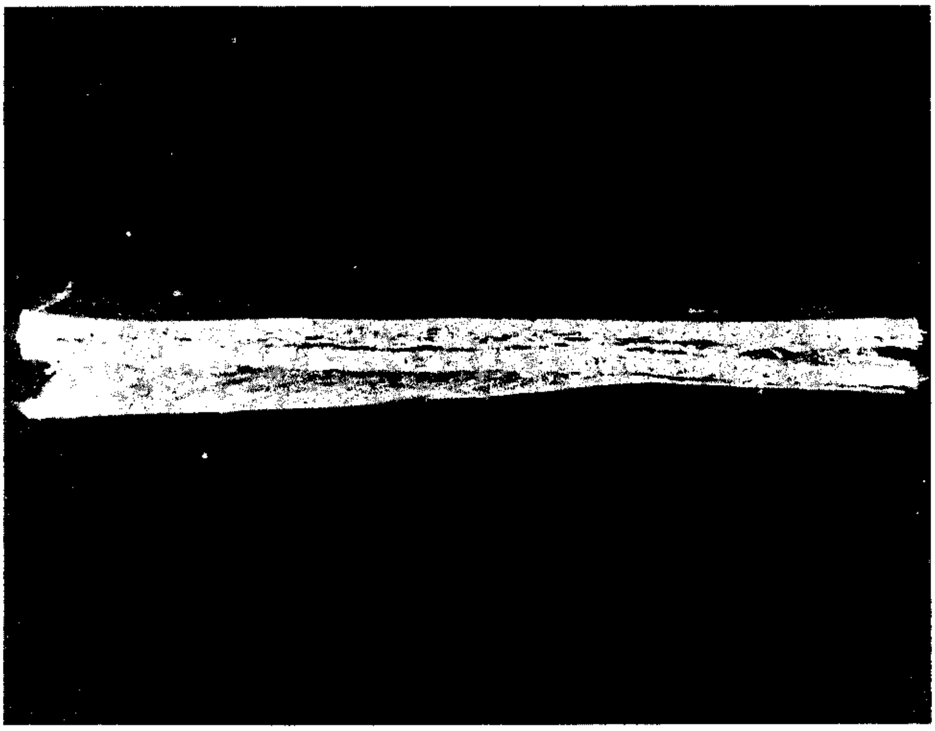


FIG. 4 DELAMINATION

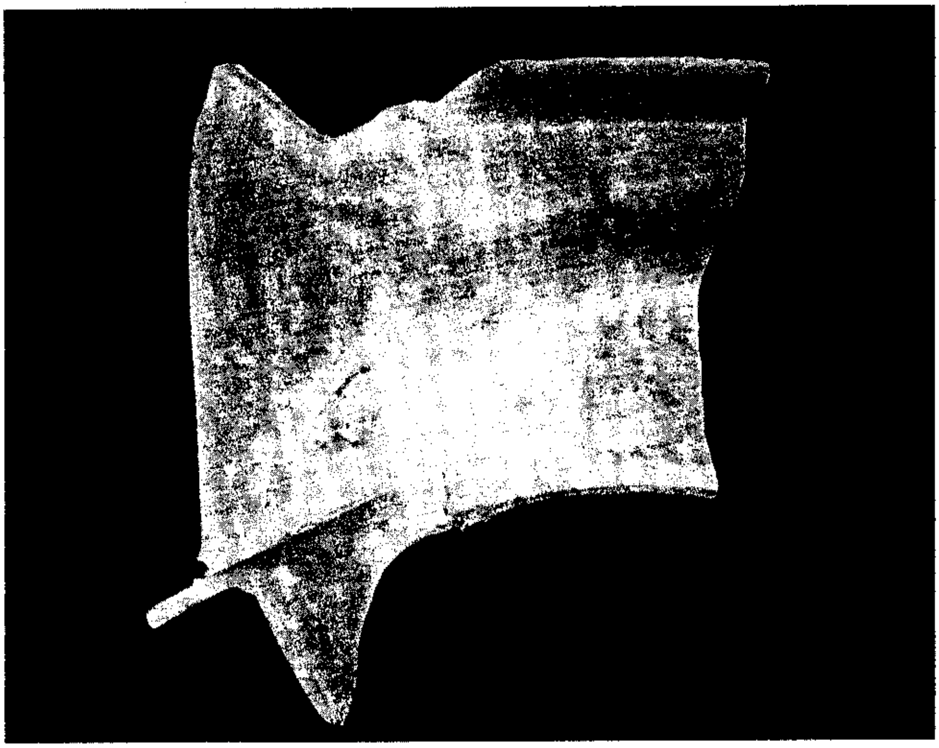


FIG. 5 DRY-SPOT

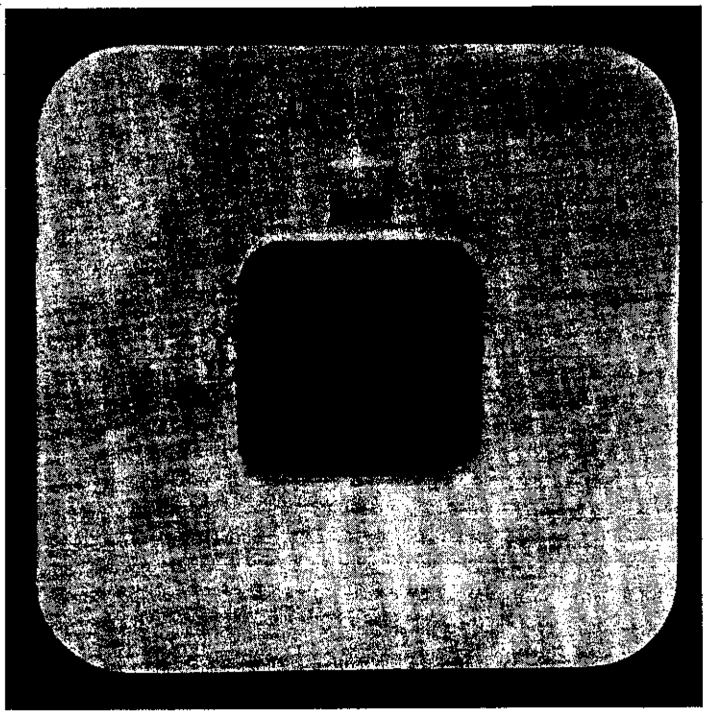


FIG. 6 FOREIGN INCLUSION

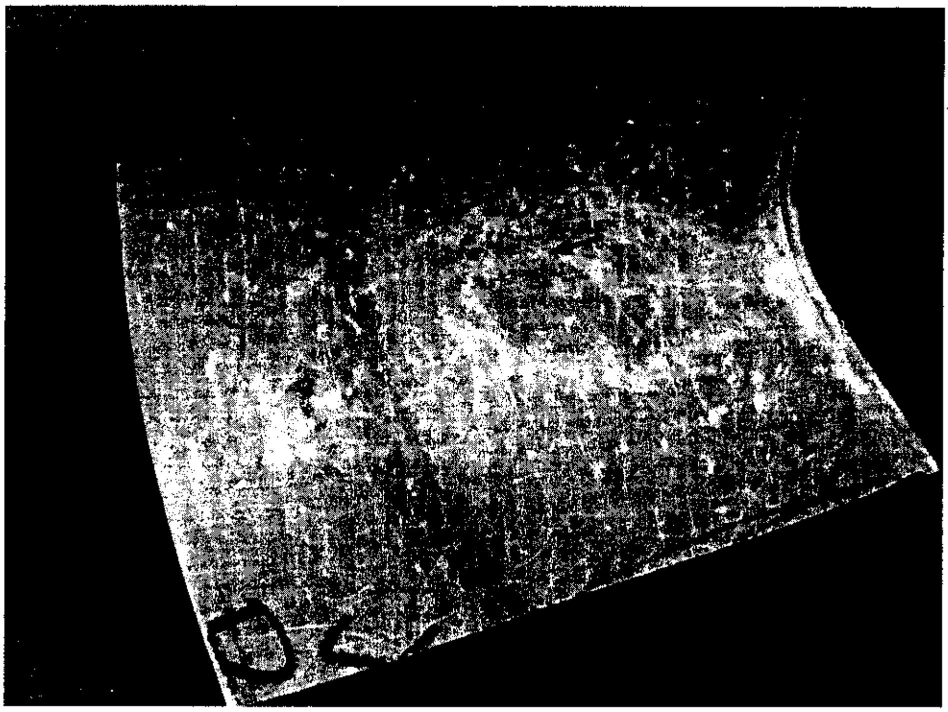


FIG. 7 FRACTURES

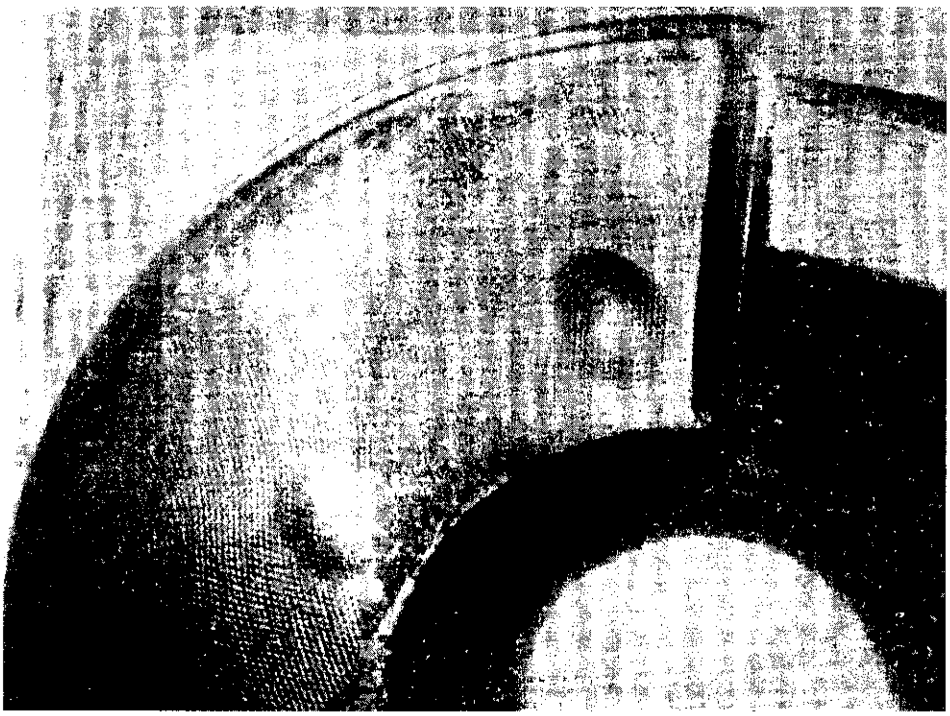


FIG. 8 BLISTER

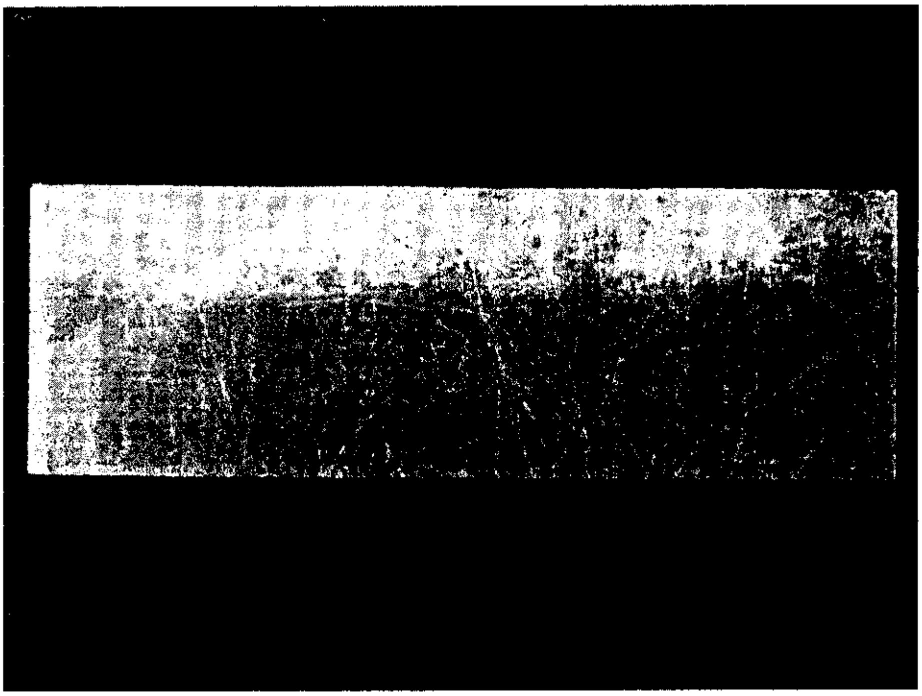


FIG. 9 EDGE SEGREGATION

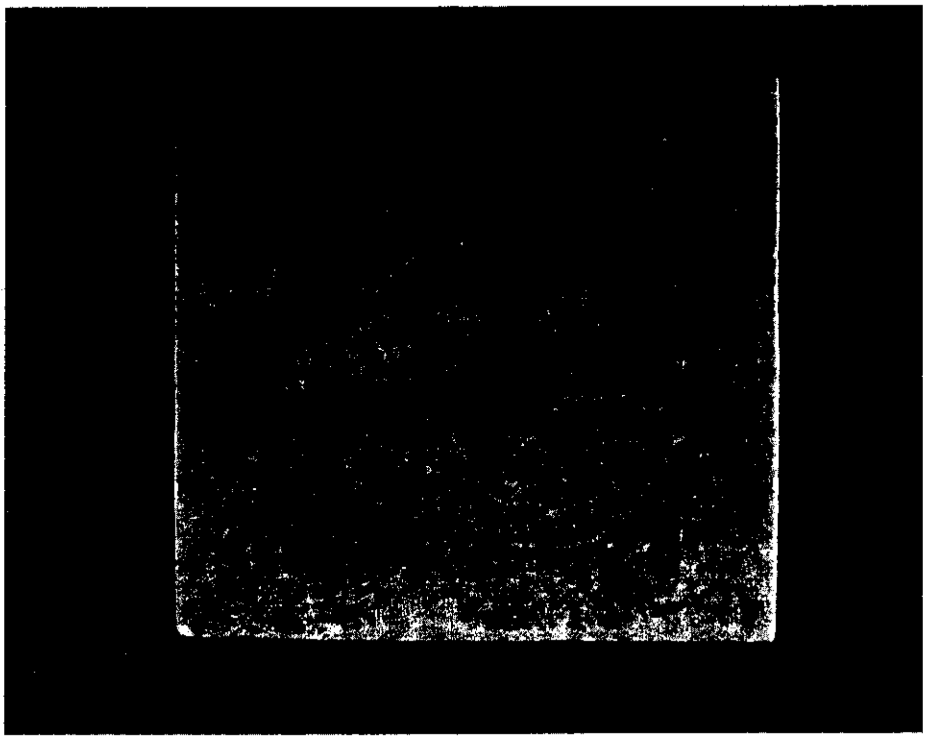


FIG. 10 FISH-EYE

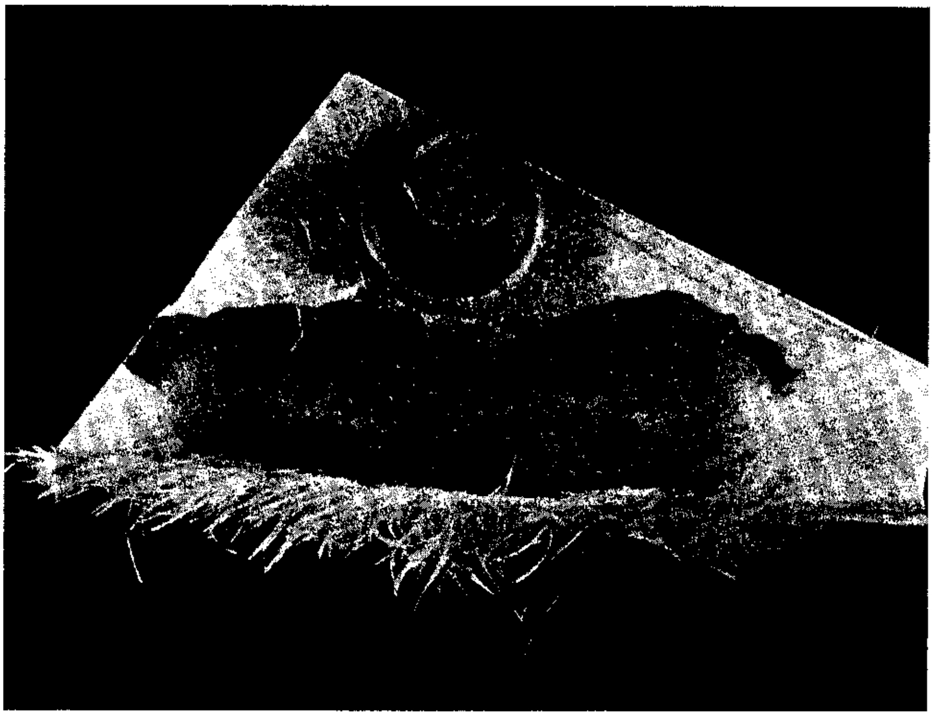


FIG. 11 LACK OF FILLOUT

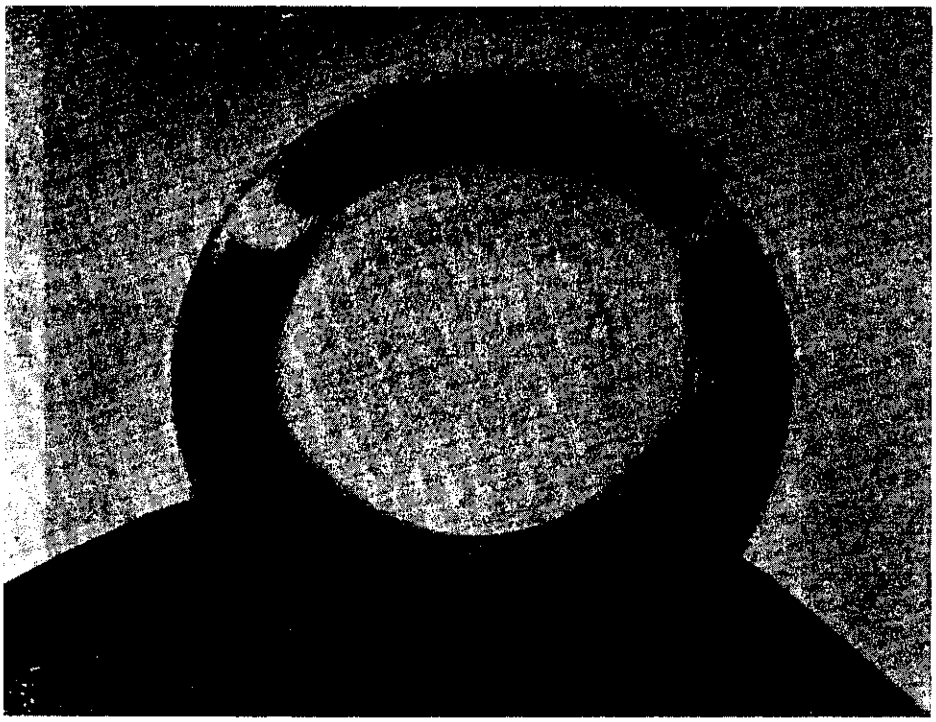


FIG. 12 POROSITY

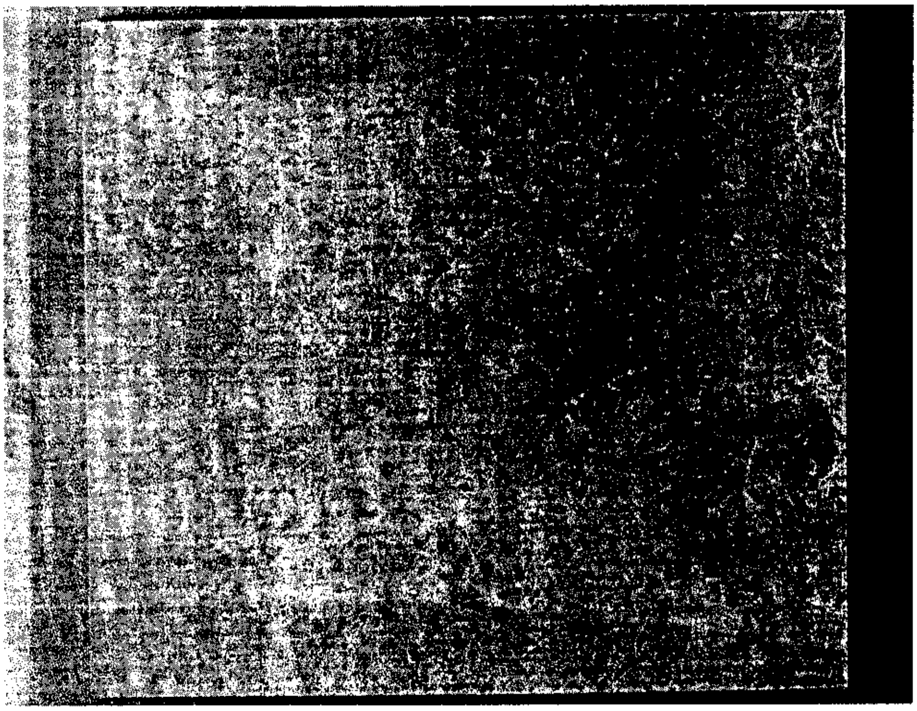


FIG. 13 PRE-GEL

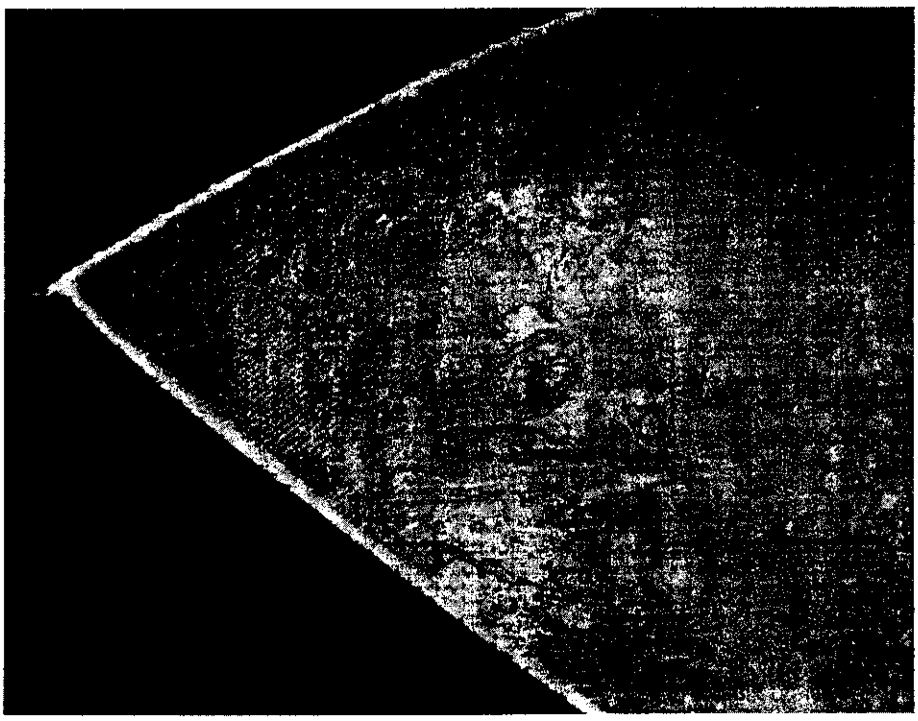


FIG. 14 RESIN-POCKET

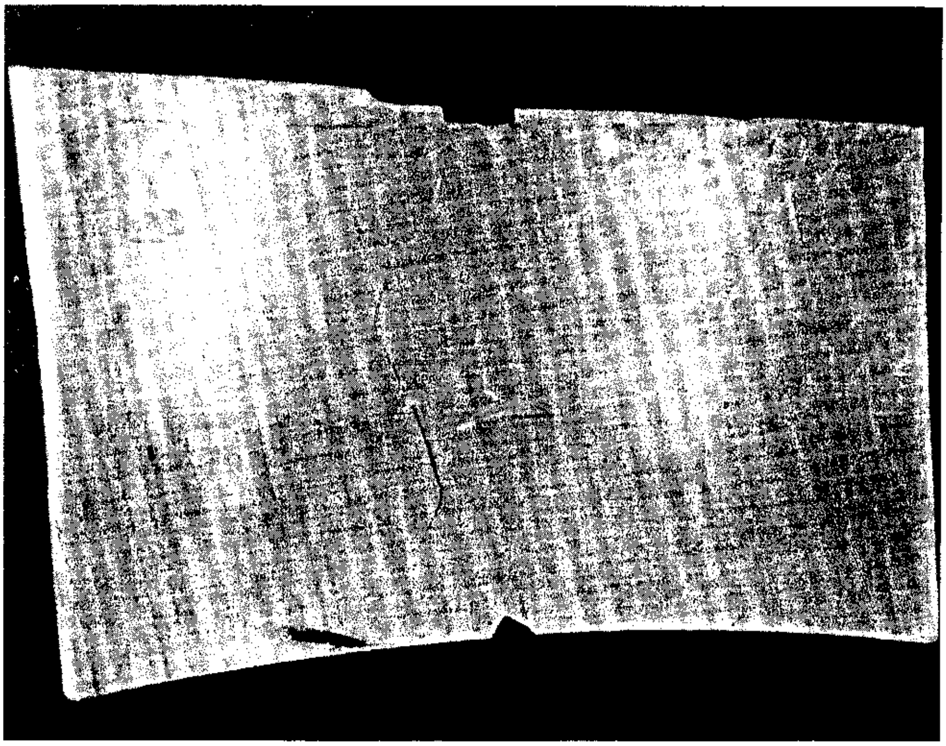


FIG. 15 RESIN-RICH CRACK

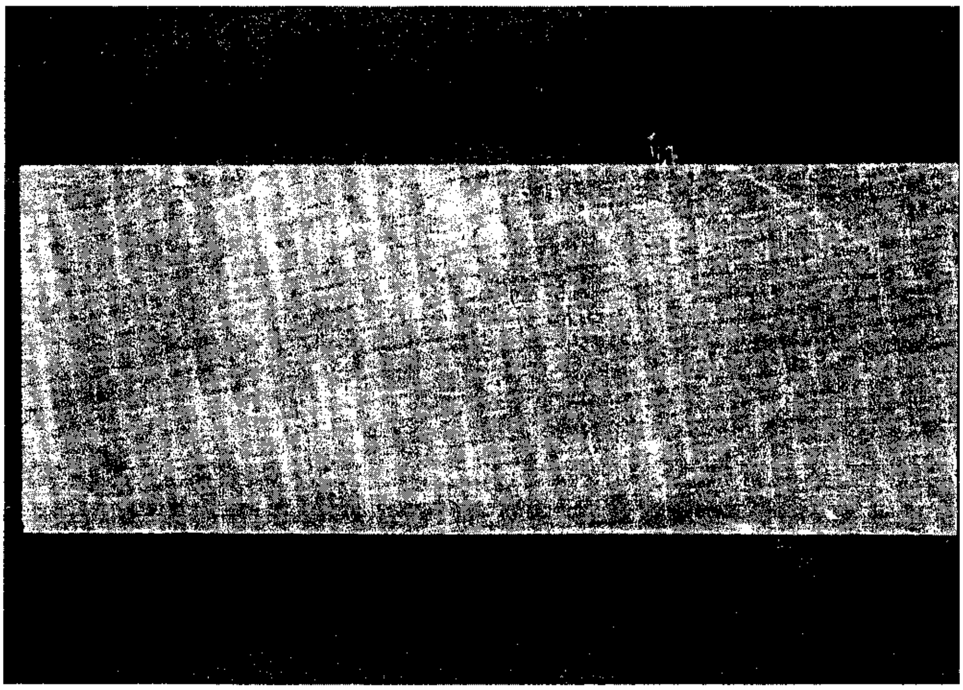


FIG. 16 RESIN-RICH EDGE

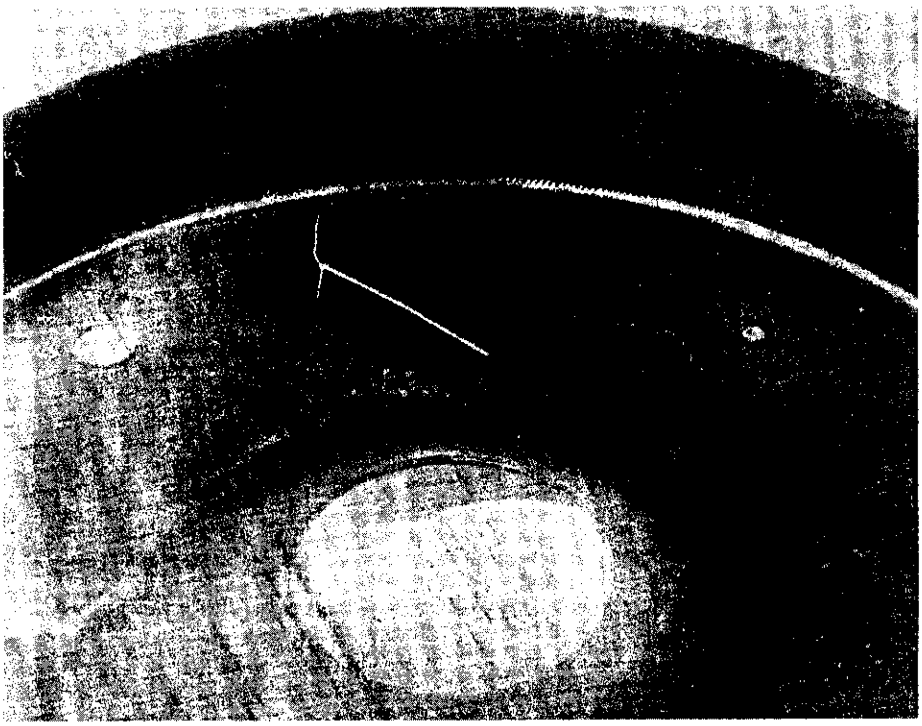


FIG. 17 SCRATCH

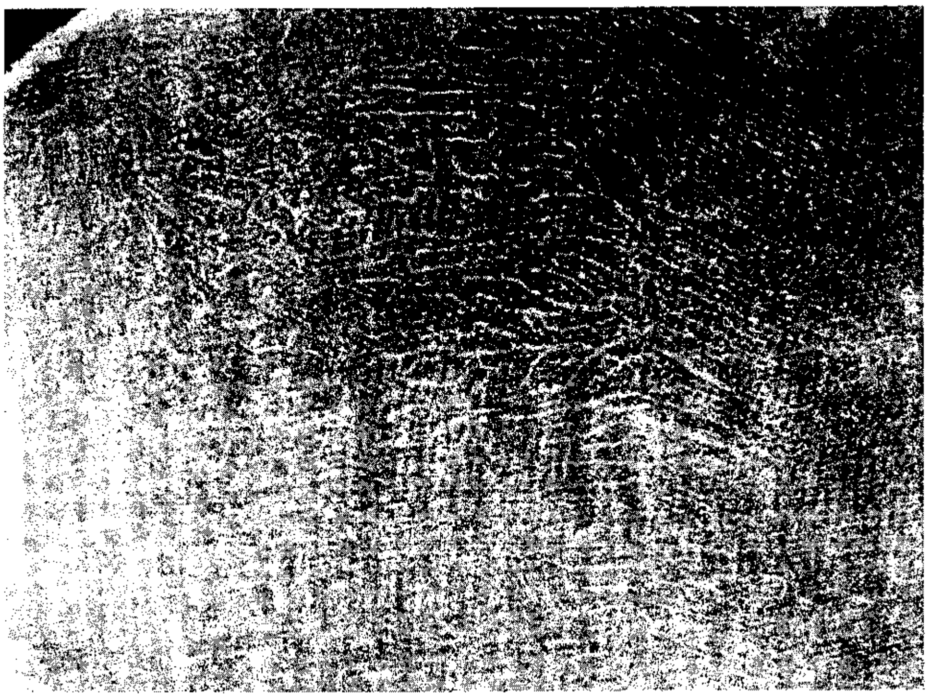


FIG. 18 SHRINK MARKS

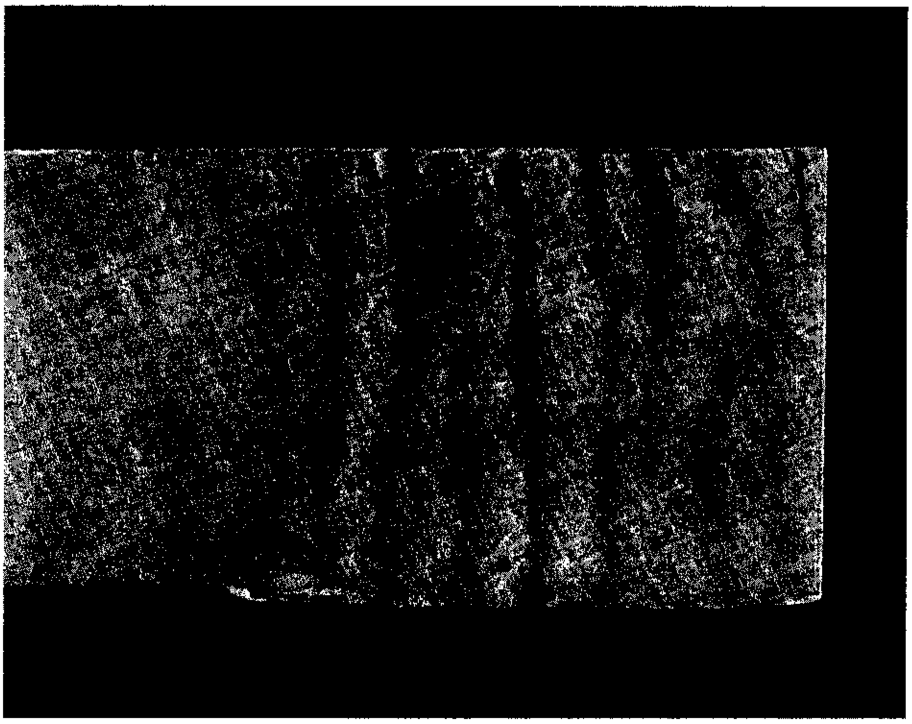


FIG. 19 WASH

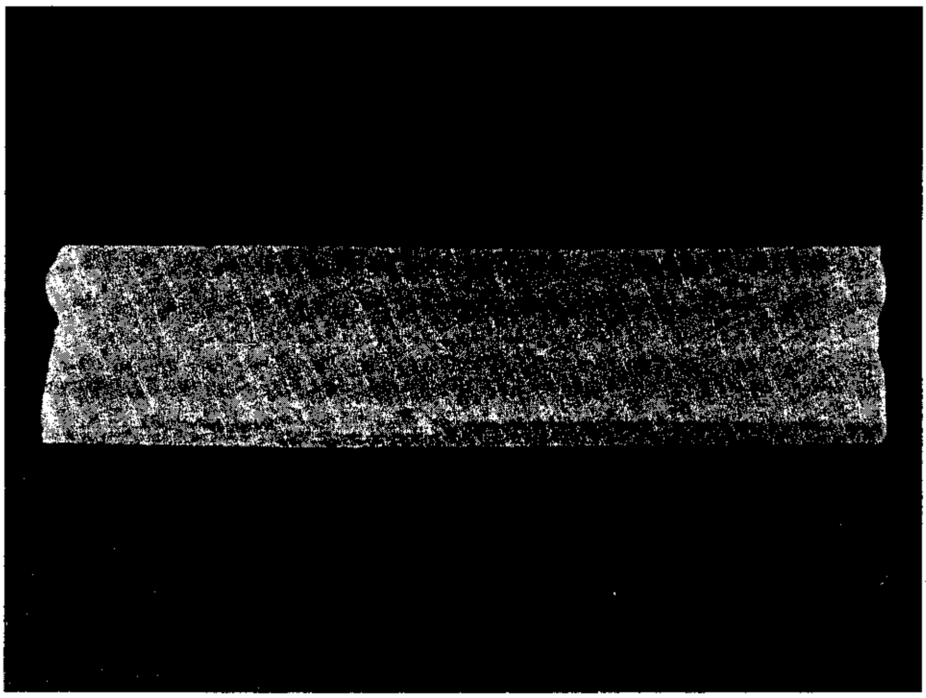


FIG. 20 WORMHOLE

FIG. 21 WRINKLES

ARTICLE 29
ACOUSTIC EMISSION STANDARDS

STANDARD GUIDE FOR MOUNTING PIEZOELECTRIC ACOUSTIC EMISSION SENSORS

SE-650

(Identical with ASTM Specification E 650-97)

1. Scope

1.1 This document provides guidelines for mounting piezoelectric acoustic emission (AE) sensors.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response

E 1316 Terminology for Nondestructive Examinations

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *bonding agent* — a couplant that physically attaches the sensor to the structure.

3.1.2 *couplant* — a material used at the structure-to-sensor interface to improve the transfer of acoustic energy across the interface.

3.1.3 *mounting fixture* — a device that holds the sensor in place on the structure to be monitored.

3.1.4 *sensor* — a detection device that transforms the particle motion produced by an elastic wave into an electrical signal.

3.1.5 *waveguide, acoustic* — a device that couples acoustic energy from a structure to a remotely mounted sensor. For example, a solid wire or rod, coupled to a sensor at one end and to the structure at the other.

3.2 *Definitions:*

3.2.1 For definitions of additional terms relating to acoustic emission, refer to Terminology E 1316.

4. Significance and Use

4.1 The methods and procedures used in mounting AE sensors can have significant effects upon the performance of those sensors. Optimum and reproducible detection of AE requires both appropriate sensor-mounting fixtures and consistent sensor-mounting procedures.

5. Mounting Methods

5.1 The purpose of the mounting method is to hold the sensor in a fixed position on a structure and to ensure that the acoustic coupling between the sensor and the structure is both adequate and constant. Mounting methods will generally fall into one of the following categories:

5.1.1 *Compression Mounts* — The compression mount holds the sensor in intimate contact with the surface of the structure through the use of force. This force is generally supplied by springs, torqued-screw threads, magnets, tape, or elastic bands. The use of a couplant is strongly advised with a compression mount to maximize the transmission of acoustic energy through the sensor-structure interface.

5.1.2 *Bonding* — The sensor may be attached directly to the structure with a suitable adhesive. In this method, the adhesive acts as the couplant. The

adhesive must be compatible with the structure, the sensor, the environment, and the test procedure.

6. Mounting Requirements

6.1 *Sensor Selection* — The correct sensors should be chosen to optimally accomplish the acoustic-emission test objective. Sensor parameters to be considered are as follows: size, sensitivity, frequency response, surface-motion response, and environmental and material compatibility. When a multichannel acoustic-emission test is being conducted, a subset of sensors with characteristics similar to each other should be selected. See Guide E 976 for methods of comparing sensor characteristics.

6.2 *Structure Preparation* — The contacting surfaces should be cleaned and mechanically prepared. This will enhance the detection of the desired acoustic waves by assuring reliable coupling of the acoustic energy from the structure to the sensor. Preparation of these surfaces must be compatible with the construction materials used in both the sensor and the structure. Possible losses in acoustic energy transmission caused by coatings such as paint, encapsulants, loose-mill scale, weld spatter, and oxides as well as losses due to surface curvature at the contact area must be considered.

6.3 *Couplant or Bonding Agent Selection*:

6.3.1 The type of couplant or bonding agent should be selected with appropriate consideration for the effects of the environment (for example, temperature, pressure, composition of gas, or liquid environment) on the couplant and the constraints of the application. It should be chemically compatible with the structure and not be a possible cause of corrosion. In some cases, it may be a requirement that the couplant be completely removable from the surface after testing. In general, the selection of the couplant is as important from an environmental standpoint as it is from the acoustical standpoint.

6.3.2 For sensors that are primarily sensitive to particle motion perpendicular to their face, the viscosity of the couplant is not an important factor. Most liquids or greases will work as a couplant if they wet the surfaces of both the structure and the sensor. For those few sensors which are sensitive primarily to motion in the plane of their face, very high viscosity couplant or a rigid bond is recommended.

6.3.3 The thickness of the couplant may alter the effective sensitivity of the sensor. The thinnest practical layer of continuous couplant is usually the best. Care should be taken that there are no entrapped voids in the couplant. Uneveness, such as a taper from one side of the sensor to the other, can also reduce sensitivity or produce an unwanted directionality in the sensor response.

6.3.4 A useful method for applying a couplant is to place a small amount of the material in the center of the sensor face, then carefully press the sensor on to the structure surface, spreading the couplant uniformly from the center to the outside of the sensor face.

6.3.5 In some applications, it may be impractical to use a couplant because of the nature of the environment (for example, very high temperatures or extreme cleanliness requirements). In these situations, a dry contact may be used, provided sufficient mechanical force is applied to hold the sensor against the structure. The necessary contact pressure must be determined experimentally. As a rough guide, this pressure should exceed 0.7 MPa (100 psi).

6.3.6 Great care must be taken when bonding a sensor to a structure. Surface deformation, which can be produced by either mechanical loading or thermal expansion, may cause a bond to crack, peel off, or, occasionally, destroy the sensor. Bond cracking is a source of acoustic emission. A compliant adhesive may work in some cases. If differential expansion between the sensor, the bond, and the surface is a possibility, a suitable bonding agent should be confirmed by experiment.

6.3.7 When bonds are used, the possibility of damaging either the sensor or the surface of the structure during sensor removal must be considered.

6.3.8 The use of double-sided adhesive tape as a bonding agent is not recommended.

6.4 *Mounting Fixture Selection*:

6.4.1 Mounting fixtures must be constructed so that they do not create extraneous acoustic emission or mask valid acoustic emission generated in the structure being monitored.

6.4.1.1 The mount must not contain any loose parts or particles.

6.4.1.2 Permanent mounting may require special techniques to prevent sensor movement caused by environmental changes.

6.4.1.3 Detection of surface waves may be suppressed if the sensor is enclosed by a welded-on fixture or located at the bottom of a threaded hole. The mounting fixture should always be designed so that it

does not block out a significant amount of acoustic energy from any direction of interest.

6.4.2 The mounting fixture should provide support for the signal cable to prevent the cable from stressing the sensor or the electrical connectors. In the absence of a mounting fixture, some form of cable support should be provided. Care should be taken to ensure that the cable can neither vibrate nor be moved easily. False signals may be generated by the cable striking the structure and by triboelectric effects produced by cable movement.

6.4.3 Where necessary, protection from the environment should be provided for the sensor or sensor and mounting fixture.

6.4.4 The mounting fixture should not affect the integrity of the structure being monitored.

6.4.4.1 Permanently installed mounting fixtures must be constructed of a material compatible with the structure. Possible electrolytic effects or other forms of corrosion must be considered when designing the mounting fixture.

6.4.4.2 Alterations of the local environment by the mount, such as removal of the insulation, must be carefully evaluated and corrected if necessary.

6.4.5 The mounting fixture should be designed to have a minimal effect on the response characteristics of the sensor.

6.5 *Waveguides* — When adverse environments make direct contact between the sensor and the structure undesirable, an acoustic waveguide may be used to convey the acoustic signal from the structure to the sensor. The use of a waveguide inserts another interface with its associated losses between the structure and the sensor and will distort, to some degree, the characteristics of the acoustic wave.

6.5.1 An acoustic waveguide should be mounted so as to ensure that its surface will not contact any materials that will cause signal damping in the waveguide.

6.5.2 If acoustic waveguides are used when acoustic-emission source location is being performed, the extra time delay in the waveguides must be accounted for in the source location program.

7. Verification of Response

7.1 After the sensor(s) are mounted on a structure, adequate response should be verified by injecting acoustic signals into the structure and examining the detected signal either on an oscilloscope or with the AE system to be used in the test. If there is any doubt as to the sensor response, the sensor should be remounted.

7.1.1 The test signal may be injected by an external source such as the Hsu-pencil source, or a gas jet (helium or other suitable gas), or by applying an electrical pulse to another sensor mounted on the structure. For a description of these methods see Guide E 976.

7.2 *Periodic Verification* — On an extended acoustic emission test, it may be desirable to verify the response of the sensors during the test. Verification should be performed whenever circumstances indicate the possibility of a change in the coupling efficiency.

7.3 *Post Verification* — At the end of an acoustic emission test, it is good practice to verify that all sensors are still working and that there have been no dramatic changes in coupling efficiencies.

8. Report

8.1 Any report of the mounting practice should include details of the sensor mounting fixture(s), surface preparation method, and the couplant that was used.

9. Keywords

9.1 acoustic emission; acoustic emission sensors; acoustic emission transducers; AE; bonding agent; couplant; mounting fixture; waveguide

STANDARD GUIDE FOR DETERMINING THE REPRODUCIBILITY OF ACOUSTIC EMISSION SENSOR RESPONSE

SE-976

(Identical with ASTM Specification E 976-98)

1. Scope

1.1 This guide defines simple economical procedures for testing or comparing the performance of acoustic emission sensors. These procedures allow the user to check for degradation of a sensor or to select sets of sensors with nearly identical performances. The procedures are not capable of providing an absolute calibration of the sensor nor do they assure transferability of data sets between organizations.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Significance and Use

2.1 Acoustic emission data is affected by several characteristics of the instrumentation. The most obvious of these is the system sensitivity. Of all the parameters and components contributing to the sensitivity, the acoustic emission sensor is the one most subject to variation. This variation can be a result of damage or aging, or there can be variations between nominally identical sensors. To detect such variations, it is desirable to have a method for measuring the response of a sensor to an acoustic wave. Specific purposes for checking sensors include: (1) checking the stability of its response with time; (2) checking the sensor for possible damage after accident or abuse; (3) comparing a number of sensors for use in a multichannel system to ensure that their responses are adequately matched; and (4) checking the response after thermal cycling or exposure to a hostile environment. It is very important that the sensor characteristics be always measured with the same sensor cable length and impedance as well as the same preamplifier or equivalent. This guide presents several procedures for measuring sensor response. Some of these procedures require a minimum of special equipment.

3. Principles of Application

3.1 The procedures given in this guide are designed to measure the response of an acoustic emission sensor to an arbitrary but repeatable acoustic wave. These procedures in *no* way constitute a calibration of the sensor. The absolute calibration of a sensor requires a complete knowledge of the characteristics of the acoustic wave exciting the sensor or a previously calibrated reference sensor. In either case, such a calibration is beyond the scope of this guide.

3.2 The fundamental requirement for comparing sensor responses is a source of repeatable acoustic waves. The characteristics of the wave do not need to be known as long as the wave can be reproduced at will. The sources and geometries given in this guide will produce primarily compressional waves. While the sensors will respond differently to different types of waves, changes in the response to one type of wave will imply changes in the responses to other types of waves.

3.3 These procedures all use a test block or rod. Such a device provides a convenient mounting surface for the sensor and, when appropriately marked, can ensure that the source and the sensor are always posi-

tioned identically with respect to each other. The device or rod also provides mechanical loading of the sensor similar to that experienced in actual use. Care must be taken when using these devices to minimize resonances so that the characteristics of the sensor are not masked by these resonances.

3.4 These procedures allow comparison of responses only on the same test setup. No attempt should be made to compare responses on different test setups, whether in the same or separate laboratories.

4. Apparatus

4.1 The essential elements of the apparatus for these procedures are: (1) the acoustic emission sensor under test; (2) a block or rod; (3) a signal source; and (4) measuring and recording equipment.

4.1.1 Block diagrams of some of the possible experimental setups are shown in Fig. 1.

4.2 *Blocks* — The design of the block is not critical. However, the use of a "nonresonant" block is recommended for use with an ultrasonic transducer and is required when the transducer drive uses any form of coherent electrical signal.

4.2.1 *Conical "Nonresonant" Block* — The Beattie block, shown in Fig. 2, can be machined from a 10 cm (4 in.) diameter metal billet. The preferred materials are aluminum and low-alloy steel. After the bottom is faced and the taper cut, the block is clamped at a 10° angle and the top face is milled. The dimensions given will provide an approximate circle just over 2.5 cm (1 in.) in diameter for mounting the sensor. The acoustic excitation should be applied at the center of the bottom face. The conic geometry and lack of any parallel surfaces reduce the number of mechanical resonances that the block can support. A further reduction in possible resonances of the block can be achieved by roughly machining all surfaces except where the sensor and exciter are mounted and coating them with a layer of metal-filled epoxy.

4.2.2 *Gas-Jet Test Block* — Two gas-jet test blocks are shown in Fig. 3. The block shown in Fig. 3(a) is used for opposite surface comparisons, which produce primarily compressional waves. That shown in Fig. 3(b) is for same surface comparisons which produce primarily surface waves. The "nonresonant" block described in 4.2.1 can also be used with a gas jet in order to avoid exciting many resonant modes. The blocks in Fig. 3 have been used successfully but their design is not critical. However, it is suggested that the relative positions of the sensor and the jet be retained.

4.2.3 *Acrylic Polymer Rod* — A polymethylmethacrylate rod 152.4 cm (60 in.) long by 3.81 cm (1.5 in.) in diameter is shown in Fig. 4. The sensor is mounted on the end of the rod and the acoustic excitation is applied by means of pencil lead break, 10.16 cm ± 0.5 mm (4.0 ± 0.02 in.) from the sensor end of the rod. In order to avoid rod acoustic property changes, the technique should be used only within a narrow temperature range, for example 15 to 30°C (60 to 85°F).

4.3 *Signal Sources* — Three signal sources are recommended: an electrically driven ultrasonic transducer, a gas jet, and an impulsive source produced by breaking a pencil lead.

4.3.1 *Ultrasonic Transducer* — Repeatable acoustic waves can be produced by an ultrasonic transducer permanently bonded to a test block. The transducer should be heavily damped to provide a broad frequency response and have a center frequency in the 2.25 to 5.0 MHz range. The diameter of the active element should be at least 1.25 cm (0.5 in.) to provide measurable signal strength at the position of the sensor under test. The ultrasonic transducer should be checked for adequate response in the 50 to 200 kHz region before permanent bonding to the test block.

4.3.1.1 *White Noise Generator* — An ultrasonic transducer driven by a white noise generator produces an acoustic wave that lacks coherent wave trains of many wavelengths at one frequency. This lack of coherent wave trains greatly reduces the number and strength of the mechanical resonances excited in a structure. Therefore, an ultrasonic transducer driven by a white noise generator can be used with a resonant block having parallel sides. However, the use of a "nonresonant" block such as that described in 4.2.1 is strongly recommended. The generator should have a white noise spectrum covering at least the frequency range from 10 kHz to 2 MHz and be capable of an output level of 1 V rms.

4.3.1.2 *Sweep Generator* — The ultrasonic transducer can be driven by a sweep generator in conjunction with a "nonresonant" block. Even with this block, some resonances will be produced that may partially mask the response of the sensor under test. The sweep generator should have a maximum frequency of at least 2 MHz and the sweep speed should be compatible with the XY recorder used. It is recommended that a

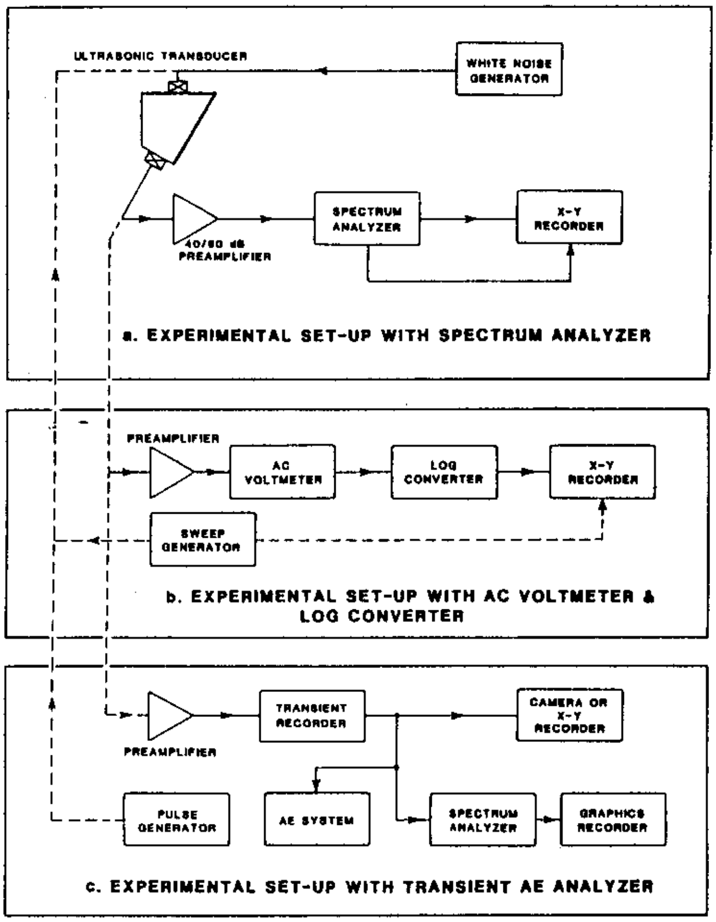


FIG. 1 BLOCK DIAGRAMS OF POSSIBLE EXPERIMENTAL SETUPS

sweep generator be used with an a-c voltmeter with a logarithmic output.

4.3.1.3 *Pulse Generator* — The ultrasonic transducer may be excited by a pulse generator. The pulse width should be either slightly less than one-half the period of the center frequency of the transducer (≤ 0.22 μs for a 2.25 MHz transducer) or longer than the damping time of the sensor, block, and transducer (typically > 10 ms). The pulse repetition rate should be low (< 100 pulses/s) so that each acoustic wave train is damped out before the next one is excited.

4.3.1.4 The pulse generator should be used with an oscilloscope and camera or, in single-pulse mode, with the counter in an acoustic emission system. Not enough energy is generated above 200 kHz for effective use with a spectrum analyzer.

4.3.2 *Gas Jet* — Suitable gases for this apparatus are extra dry air, helium, etc. A pressure between 150 and 200 kPa (20 to 30 psi) is recommended for helium or extra dry air. Once a pressure and a gas have been chosen, all further tests with the apparatus should use that gas and pressure. The gas jet should be permanently attached to the test block [see Figs. 3(a) and 3(b)].

4.3.3 *Pencil Lead Break* — A repeatable acoustic wave can be generated by carefully breaking a pencil lead against the test block. When the lead breaks, there is a sudden release of the stress on the surface of the block where the lead is touching. This stress release generates an acoustic wave. The Hsu pencil source uses a mechanical pencil with a 0.3 mm diameter lead (0.5 mm lead is also acceptable but produces a larger signal). The Nielsen shoe, shown in Fig. 5, can aid in breaking the lead consistently. Care should be taken

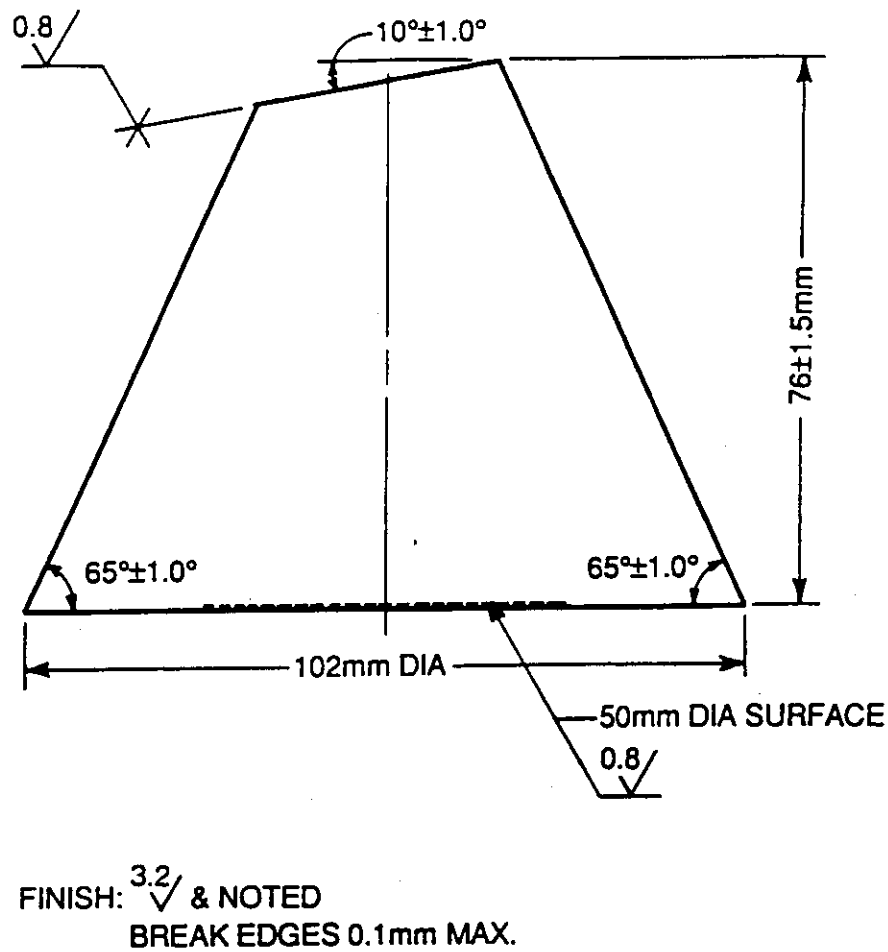


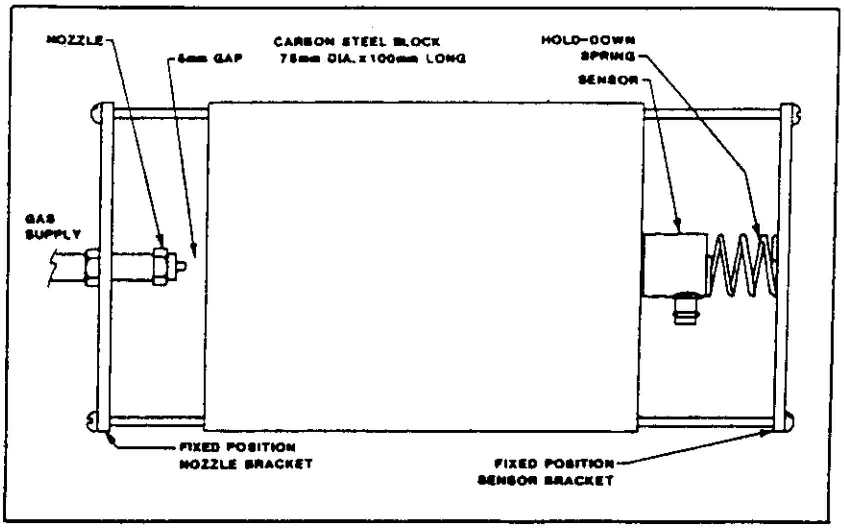
FIG. 2 THE BEATTIE BLOCK

to always break the same length of the same type of lead (lengths between 2 and 3 mm are preferred). The lead should always be broken at the same spot on the block with the same angle and orientation of the pencil. The most desirable permanent record of a pencil lead break is the wave form captured by a transient recorder or oscilloscope.

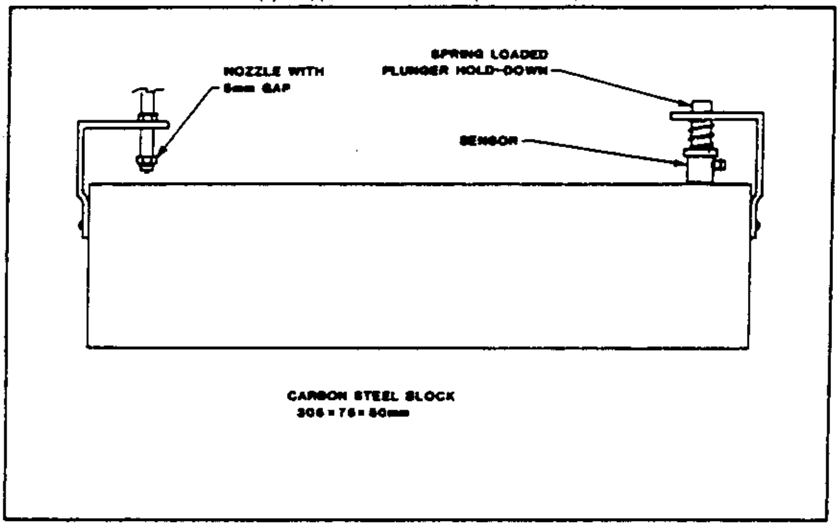
4.4 *Measuring and Recording Equipment* — The output of the sensor under test must be amplified before it can be measured. After the measurement, the results should be stored in a form that allows an easy comparison, either with another sensor or with the same sensor at a different time.

4.4.1 *Preamplifier* — The preamplifier, together with the sensor to preamp coaxial cable, provides an electrical load for the sensor, amplifies the output, and filters out unwanted frequencies. The electrical load on the sensor can distort the low-frequency response of a sensor with low inherent capacitance. To prevent this from occurring, it is recommended that short sensor cables (< 2 m) be used and the resistive component of the preamplifier input impedance be 20 $k\Omega$ or greater. The preamplifier gain should be fixed. Either 40 to 60 dB gains are suitable for most sensors. The bandpass of the preamplifier should be at least 20 to 1200 kHz. It is recommended that one preamplifier be set aside to be used exclusively in the test setup. However, it may be appropriate at times to test a sensor with the preamplifier assigned to it in an experiment.

4.4.2 *Spectrum Analyzers* — A very useful instrument for testing sensor response is the spectrum analyzer. Spectrum analyzers can be used with acoustic signals generated by ultrasonic transducers that are driven by either white noise generators or tracking-



(a) Opposite Surface Comparison Setup



(b) Same Surface Comparison Test

FIG. 3 GAS-JET TEST BLOCKS

sweep generators, by gas-jet sources or by acoustic signals, produced by any source, that are captured on a transient recorder and replayed into the spectrum analyzer. A suitable spectrum analyzer should be capable of displaying a spectrum covering the frequency range from 20 kHz to 1.2 MHz. The amplitude should be displayed on a logarithmic scale covering a range from at least 50 dB in order to display the entire dynamic range of the sensor. The spectrum can be recorded photographically from an oscilloscope. However, the most useful output is an XY plot of the spectrum as shown in Fig. 6.

4.4.3 *Voltmeters* — An a-c voltmeter can be used to measure sensor outputs produced by signals generated by an ultrasonic transducer driven by a sweep generator. The response of the voltmeter should be flat over the frequency range from 10 kHz to 2 MHz. It is desirable that the voltmeter either have a logarithmic output or be capable of driving a logarithmic converter. The output of the voltmeter or converter is recorded on an XY recorder as a function of frequency.

4.4.3.1 The limited dynamic range of an rms voltmeter makes it less desirable than an a-c averaging

voltmeter when used with a sweep generator. However, a rough estimate of a sensor performance can be obtained by using an rms or a-c voltmeter to measure the output of a sensor driven by a wide band source such as a white noise generator or a gas jet.

4.4.4 *Acoustic Emission System* — A sensor can be characterized by using an acoustic emission system and an impulsive source such as a pencil lead break, an ultrasonic (or AE) transducer driven by a pulse generator, or the impulsive source that is built into many AE systems with automated pulsing capabilities. One or more of several significant AE signal features (such as amplitude, counts, or energy) can be used to characterize the sensor response. The acoustic emission features from each signal pulse should be measured for multiple pulses (at least three). Data recorded should be the individual AE feature values (for repeatability determination) and average value of the readings (for sensitivity determination). In addition, the system gain, preamplifier gain, filtering, and any other significant settings of the acoustic emission system should be recorded.

4.4.5 *Transient Recorders and Storage Oscilloscopes* — The waveform generated by a sensor in response to a single pulse or a pencil lead break can be measured and stored by a transient recorder, digital oscilloscope, or a waveform-based acoustic emission system. This waveform can be recorded on computer media, displayed on a computer screen, or printed out on a printer or X-Y recorder. Digitization rates should be at least 10 samples per highest frequency period in the waveform. Lower rates might result in distortion or loss of amplitude accuracy of the wave shape. When comparing waveforms, emphasis should be placed on the initial few cycles and on the large amplitude features. Small variations late in the waveform are often produced by slight changes in the coupling or position of the sensor under test. The waveform can also be converted into the frequency domain by means of a fast fourier transform (FFT) for amplitude versus frequency response analysis.

5. Procedure

5.1 Place the sensors under test on the test block in as near to identical positions as possible. Use identical forces to hold the sensor and block together. A low-viscosity couplant is desirable to ensure reproducible and thin couplant thicknesses. For all setups, take several measurements before the final data is recorded to ensure reproducibility. During the initial measurements, display the preamplifier output on an oscilloscope to see that the signals are not being clipped by overdriving the preamplifier. Establish written procedures and follow them to ensure reproducibility over long periods of time.

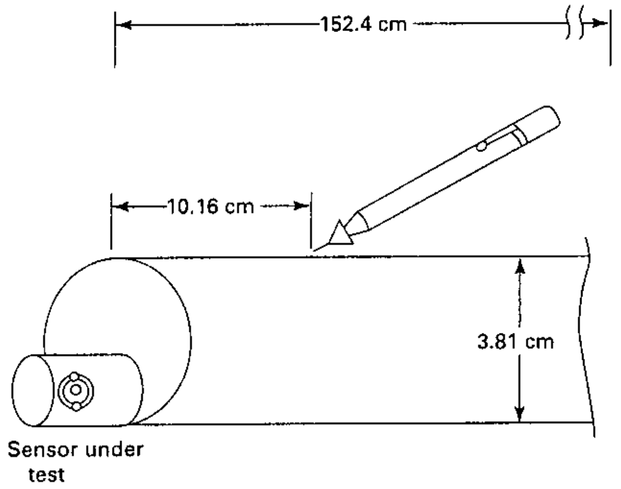
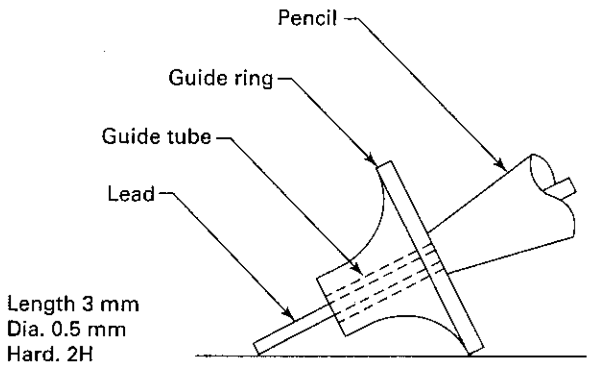


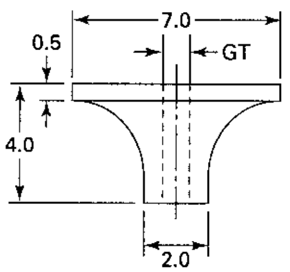
FIG. 4 ACRYLIC POLYMER ROD

6. Interpretation of Results

6.1 Short-term reproducibility of results, covering such actions as removing and remounting the sensor, should be better than 3 dB if the test is conducted under normal working conditions. Long-term reproducibility of the test system should be checked periodically by the use of a reference sensor that is not exposed to the risk of environmental damage. Variations of sensor response greater than 4 dB indicates damage or degradation, and the cause of the discrepancy should be further investigated. While there are no set criteria for acceptable limits on sensor degradation, a sensor whose sensitivity had fallen by more than 6 dB would generally be considered unfit for further service in acoustic emission measurements.



(a) Nielsen Shoe on Hsu Pencil Source



Diameter	GT (±0.05 mm)
0.3 mm	0.84 mm
0.5 mm	0.92 mm

Guide ring
Teflon
Dimensions given in mm
Tolerances ± 0.1 mm
(unless otherwise noted)

(b) Nielsen Shoe

FIG. 5 GUIDE RING FOR IMPULSIVE SOURCE

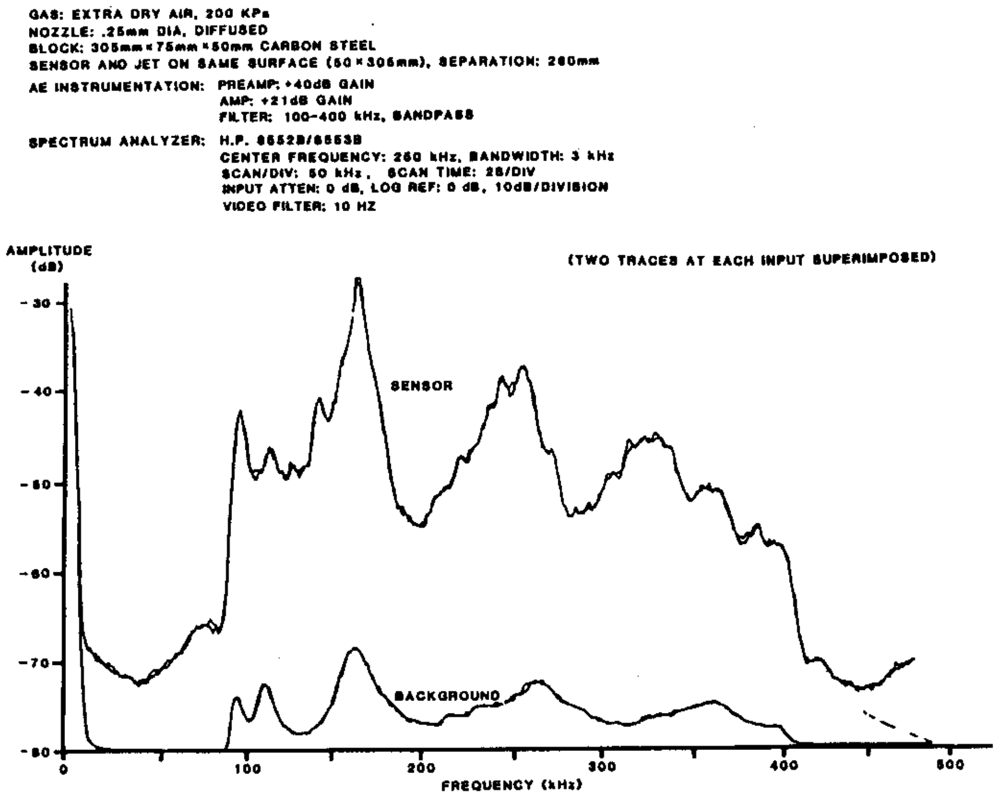


FIG. 6 EXAMPLE OF AN X-Y RECORDER PLOT FROM A SPECTRUM ANALYZER (150 kHz RESONANT SENSOR)

STANDARD PRACTICE FOR LEAK DETECTION AND LOCATION USING SURFACE-MOUNTED ACOUSTIC EMISSION SENSORS

SE-1211

(Identical with ASTM Specification E 1211-97)

1. Scope

1.1 This practice describes a passive method for detecting and locating the steady state source of gas and liquid leaking out of a pressurized system. The method employs surface-mounted acoustic emission sensors (for noncontact sensors, see Test Method E 1002), or sensors attached to the system via acoustic waveguides (for additional information, see Terminology E 1316), and may be used for continuous inservice monitoring and hydrotest monitoring of piping and pressure vessel systems. High sensitivities may be achieved, although the values obtainable depend on sensor spacing, background noise level, system pressure, and type of leak. This practice is not intended to provide a quantitative measure of leak rates.

1.2 The values stated in inch-pound units are to be regarded as the standard. SI units are provided for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 650 Guide for Mounting Piezoelectric Acoustic Emission Sensors
E 750 Practice for Characterizing Acoustic Emission Instrumentation
E 976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response
E 1002 Test Method for Leaks Using Ultrasonics
E 1316 Terminology for Nondestructive Examinations

2.2 *Other Documents:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification
ANSI/ASNT CP-189 ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel
MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification

3. Summary of Practice

3.1 This practice requires the use of contact sensors, amplifier electronics, and equipment to measure their output signal levels. The sensors may be mounted before or during the test period and are normally left in place once mounted rather than being moved from point to point.

3.2 Detection of a steady-state leak is based on detection of the continuous, broadband signal generated by the leak flow. Signal detection is accomplished through measurement of some input signal level, such as its root-mean-square (RMS) amplitude.

3.3 The simplest leak test procedure involves *only* detection of leaks, treating each sensor channel individually. A more complex test requires processing the signal levels from two or more sensors together to allow computation of the approximate leak location, based on the principle that the leak signal amplitude decreases as a function of distance from the source.

4. Significance and Use

4.1 Leakage of gas or liquid from a pressurized system, whether through a crack, orifice, seal break, or other opening, may involve turbulent or cavitational flow, which generates acoustic energy in both the external atmosphere and the system pressure boundary. Acoustic energy transmitted through the pressure boundary can be detected at a distance by using a suitable acoustic emission sensor.

4.2 With proper selection of frequency passband, sensitivity to leak signals can be maximized by eliminating background noise. At low frequencies, generally below 100 kHz, it is possible for a leak to excite mechanical resonances within the structure that may enhance the acoustic signals used to detect leakage.

5. Basis of Application

5.1 *Personnel Qualification* — Nondestructive testing (NDT) personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, MIL-STD-410, or a similar document. The practice or standard used and its applicable revision shall be specified in the contractual agreement between the using parties.

5.2 *Qualification of Nondestructive Agencies* — If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E 543. The applicable edition of Practice E 543 shall be specified in the contractual agreement.

6. Interferences

6.1 External or internal noise sources can affect the sensitivity of an acoustic emission leak detection system. Examples of interfering noise sources are:

6.1.1 Turbulent flow or cavitation of the internal fluid;

6.1.2 Noise from grinding or machining on the system;

6.1.3 Airborne acoustic noise, in the frequency range of the measuring system;

6.1.4 Metal impacts against, or loose parts frequently striking the pressure boundary; and

6.1.5 Electrical noise pick-up by the sensor channels.

6.2 Stability or constancy of background noise can also affect the maximum allowable sensitivity, since fluctuation in background noise determines the smallest change in level that can be detected.

6.3 The acoustic emission sensors must have stable characteristics over time and as a function of both the monitoring structure and the instrumentation system test parameters, such as temperature.

6.4 Improper sensor mounting, electronic signal conditioner noise, or improper amplifier gain levels can decrease sensitivity.

7. Basic Information

7.1 The following items must be considered in preparation and planning for monitoring:

7.1.1 Known existing leaks and their distance from the areas to be monitored should be noted so that their influence on the capabilities of the method can be evaluated.

7.1.2 Type of vessel, pipeline, or installation to be examined, together with assembly, or layout drawings, or both, giving sufficient detail to establish dimensions, changes of shape likely to affect flow characteristics, positions of welds, and the location of components such as valves or flanges, and attachments to the vessel or pipe such as pipe hangers where leaks are most likely to arise. Regions with restricted accessibility due to walls, the existence or location of cladding, insulation, or below-surface components must be specified.

7.1.3 When location of the peak is of primary interest, quantitative information regarding the leakage rates of interest, and whenever possible the type of leak, is necessary.

7.1.4 Extent of monitoring, for example, entire volume of pressure boundary, weld areas only, etc.

7.1.5 Material specifications and type of surface covering (for example, paint or other coating) to allow the acoustic propagation characteristics of the structure to be evaluated.

7.1.6 Proposed program of pressure application or process-pressure schedule, specifying the pressurization schedule together with a layout or sketch of the pressure-application system and specifying the type of fluid used during the test, for example, gas, water, or oil.

7.1.7 Time of monitoring, that is, the point(s) in the manufacturing process, or service life at which the system will be monitored, or both.

7.1.8 Frequency range to be used in the monitoring equipment.

7.1.9 Environmental conditions during examination that may affect instrumentation and interpretation of results; for example, temperature, moisture, radioactivity, vibration, pressure, and electromagnetic interference.

7.1.10 Limitations or restrictions on the sensor-mounting procedure, if applicable, including restrictions on couplant materials.

7.1.11 The location of sensors or waveguides and preparation for their installation to provide adequate coverage of the areas specified in 7.1.3. Where particular sections are to be examined with particular sensors, the coverage of the vessel or system by sensor subgroups shall be specified. The sensor locations must be given as soon as possible, to allow positioning difficulties to be identified.

7.1.12 The communications procedure between the acoustic emission staff and the control staff, the time intervals at which pressure readings are to be taken, and the procedure for giving warning of unexpected variations in the pressure system.

7.1.13 Requirements for permanent records, if applicable.

7.1.14 Content and format of test report, if required.

7.1.15 Acoustic Emission Examiner qualifications and certification, if required.

8. Apparatus

8.1 *Sensors* — The acoustic emission sensors are generally piezoelectric devices and should be mounted in accordance with Practice E 650 to ensure proper signal coupling. The frequency range of the sensors may be as high as 1 MHz, and either wideband or resonant sensors may be employed. The higher frequencies can be used to achieve greater discrimination against airborne or mechanical background noise.

8.2 *Amplifiers* — Amplifiers should have sufficient gain to allow the signal processing equipment to detect the level of acoustic background noise on the pressurized system. The sensor/amplifier bandwidth should be selected to minimize background noise.

8.3 *Signal Processor* — The signal processor measures the RMS level, the acoustic emission signal power, the average signal level, or any other similar parameters of the continuous signal. A leak location processor to compute the source location from signal levels and attenuation data may be included. Alarm set points may also be included as a processor function.

8.4 *Leak Signal Simulator:*

8.4.1 A device for simulating leaks should be included to evaluate the effectiveness of the monitor system. The following could be considered: a sensor on the pressure boundary driven from a random noise generator, a small water jet, or a gas jet.

8.4.2 When leak location processing is to be performed, leak simulation should be carried out initially over a sufficiently large number of diverse points to verify proper operation of the location algorithm.

9. Verification of Equipment Performance

9.1 Characterization consists of two stages. The first stage concerns periodic calibration and verification of the equipment under laboratory conditions. This procedure is beyond the scope of this practice (see Practice E 750) but the results must be made available to the system owners if requested. The second stage concerns in-situ verification to check the sensitivities of all channels and the satisfactory operation of the detection equipment. For every calibration operation, a written procedure shall be prepared.

9.2 In-situ sensitivity check of all sensors should be performed by placing a leak signal simulator (see Guide E 976) at a specified distance from each sensor and recording the resulting output level from the amplifier, as referred to the amplifier input terminal. Amplifier gains may also be adjusted as appropriate to correct for sensitivity variations.

9.3 Periodic sensitivity checks shall be made during long tests (days) or if any environmental changes occur. The relative sensitivity check is accomplished by driving various sensors or activating various leak simulation devices, such as water or gas jets, and measuring the outputs of the receiving sensors. The ratio of the outputs of two receiving sensors for a given injection point should remain constant over time. Any change in the ratio indicates a deviation in performance. In this way, all sensors on a system may be compared to one or several reference signals and proper adjustments made (see Guide E 976).

9.4 When leak location calculations are to be performed, the acoustic attenuation between sensors should be characterized over the frequency band of interest, especially if the presence of discontinuities, such as pipe joints, may be suspected to affect the uniformity

of attenuation. The measurements should then be factored into the source location algorithm.

10. Procedure

10.1 *Pre-Examination Requirements:*

10.1.1 Before beginning the acoustic emission monitoring, ensure that the following requirements are met:

10.1.1.1 Evaluate attenuation effects, that is, the change in signal amplitude with sound-propagation distance, so as to define the effective area covered by each individual sensor; and in the case of sensor subgroups, the maximum distance between sensing points.

10.1.1.2 Ensure that sensors are placed at the predetermined positions. If it is necessary to modify these positions during installation, record the new sensor locations. Record the method of attachment of the sensors and the couplant used.

10.1.1.3 Review the operating schedule to identify all potential sources of extraneous acoustic noise such as nozzle-plug movement, pump vibration, valve stroking, personnel movement, fluid flow, and turbulence. Such sources may require acoustic isolation or control so that they will not mask relevant leak emission within the vessel or structure being examined. Uncontrolled generation of acoustic interference by conditions such as rain, sleet, hail, sand, wind (for unprotected vessels), chipping, or grinding, shall be evaluated and its effect minimized by acoustic isolation insofar as is practical. A record shall be made of such sources.

10.2 *Acoustic Emission Monitoring:*

10.2.1 The noise level of each channel or each group shall be continuously or periodically recorded, as required. Pressure or other significant parameters, or both, will normally be recorded to allow correlation with the acoustic emission data response.

10.2.2 When an increase in noise level attributable to a leak has been detected, the examiner shall inform the system owner who will then look for the origin of the leak and its nature. If the leak is found to be outside the area of interest on the structure being monitored (extraneous leak), it must be stopped or reduced to a level necessary to ensure satisfactory monitoring. If extraneous leaks cannot be stopped, then the effect of such signals on the acoustic emission system sensitivity shall be noted. A report shall be prepared following the visual (or other) examination for leaks.

11. Report

11.1 Report the following information:

11.1.1 date of examination,

11.1.2 identity of examining personnel,

11.1.3 sensor characteristics and locations,

11.1.4 method of coupling sensors to the structure,

11.1.5 acoustic emission system and its characteristics,

11.1.6 operating conditions,

11.1.7 initial calibration results (laboratory),

11.1.8 in-situ calibration results and equipment verification,

11.1.9 results of measurements,

11.1.10 analysis and verification of results,

11.1.11 results of visual (or other) examination(s),

11.1.12 presentation of the numbers and locations of leaks detected,

11.1.13 analysis of background noise measurements,

11.1.14 estimate of quality of measurement and causes of any reduced sensitivity, and

11.1.15 conclusions and recommendations.

12. Keywords

12.1 acoustic emission; continuous monitoring; hydrotest; leak detection; nondestructive testing; piping systems; pressure vessels.

APPENDIX

(Nonmandatory Information)

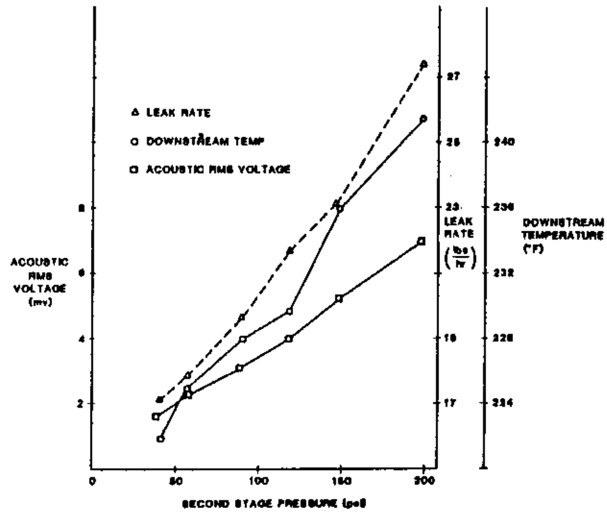
X1. APPLICATIONS EXAMPLES

X1.1 The following examples were selected to illustrate application of acoustic emission leak detection, and are not intended to provide detailed descriptions of the application.

X1.1.1 *Acoustic Emission Leak Detection of a Safety/Relief Valve* — A safety/relief valve having a leaking pilot-disk seat was tested under laboratory conditions in order to determine the correlation of the leak noise with leak rate or second-stage pressure. The leak rate, downstream temperature, and the RMS voltage of the acoustic signal were plotted against the second-stage pressure in Fig. X1.1. The acoustic emission sensor was clamped onto the external housing of the pilot works. The signal was band-pass filtered in the range from 5 to 10 kHz. The downstream temperature was measured by a thermocouple in the vicinity of the "pilot valve discharge line." As the second stage pressure increased from 40 to 200 psi (280 to 1400 kPa), the leak rate increased 59%, the temperature increased 9%, and the acoustic emission RMS voltage increased 370%. Therefore, the sensitivity of the acoustic detection was excellent (see Fig. X1.1).

X1.1.2 *Acoustic Emission Leak Detection from Seawater Ball Valves* — The U.S. Navy Acoustic Valve Leak Detector (AVLD) monitors leak-associated acoustic emission energy in the frequency range of 10 to 100 kHz. This frequency range was chosen because there is significant energy emitted by leaky valves, and energy in this range is rapidly attenuated with increasing distance from the source. Therefore, background noise can be electronically separated from the signal. Figure X1.2 shows the estimated leak rate versus acoustic emission level for a 4 in. ball valve.

X1.1.3 *Acoustic Emission Leak Detection of a Submerged Crude Oil Transfer Line* — A section of 12 in. diameter steel pipe terminating on an offshore drilling platform was inspected for confirmation of a suspected leak. During acceptance hydrotesting of the line, it was noted that pressure decayed at about 60 psi/h (410 kPa/h) starting at about 3200 psig (22 MPa). The suspected source of leakage was at the spool piece flanges. Signal level readings were taken on the 12 in.



NOTE 1—0°F = 32°C.
NOTE 2—1 psi = 6.9 kPa.

FIG. X1.1 EXAMPLE OF ACOUSTIC EMISSION LEAK DETECTION IN A SAFETY/RELIEF VALVE OF A NUCLEAR POWER PLANT

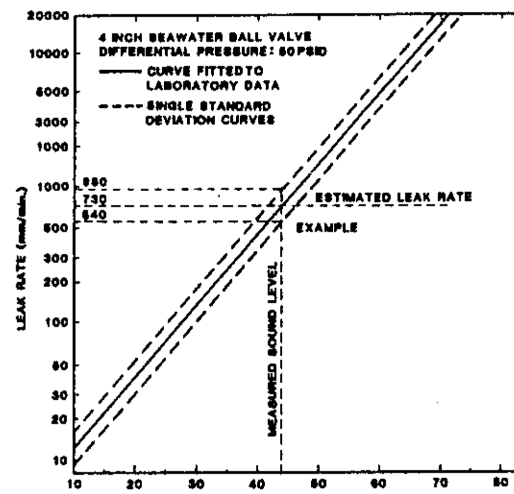


FIG. X1.2 ESTIMATING LEAK RATE FROM ACOUSTIC EMISSION LEVEL IN 4 in. SEAWATER BALL VALVES

riser on the platform after the pressure on the pipe was elevated to 3200 psig (22 MPa). These signal readings were compared with readings taken on two adjacent pipes, and on the nearest support leg for the structure (see Table X1.1). The additional readings were used to determine the amount of signal that was caused by sea motion and other structural interfering noise. The initial readings were taken with the platform in a shut-down condition and all construction workers on-shore. The readings indicated about a 50% increase in signal level on the leaking pipe as compared to the other two risers and the support leg. This indicated leakage in close proximity to the detection point, in effect, verifying that leakage was in the connecting spool piece flanges. Following tightening by a diver of the identified leaking flange, the acoustic emission examiner determined that the leak had been stopped. No further indications of leakage were detected; either by mechanical means (pressure drop) or by acoustic emission.

TABLE X1.1
SIGNAL READINGS

Location	RMS Reading	Comment
6-in. pipe riser	0.200 at 60 dB gain	reference
10-in. pipe riser	0.210 at 60 dB gain	reference
12-in. pipe riser	0.300 at 60 dB gain	leaking pipe
Corner support leg	0.210 at 60 dB gain	reference
Location	**RMS Reading**	**Comment**
6-in. pipe riser	0.200 at 60 dB gain	reference
10-in. pipe riser	0.200 at 60 dB gain	reference
12-in. pipe riser	0.200 at 60 dB gain	leak noise is stopped
Corner support leg	0.210 at 60 dB gain	reference

STANDARD TEST METHOD FOR EXAMINATION OF SEAMLESS, GAS-FILLED PRESSURE VESSELS USING ACOUSTIC EMISSION

SE-1419

(Identical with ASTM Specification E 1419-96)

1. Scope

1.1 This test method provides guidelines for acoustic emission (AE) tests of seamless pressure vessels (tubes) of the type used for distribution of industrial gases.

1.2 This test method requires pressurization to a level greater than normal use. Pressurization medium may be gas or liquid.

1.3 This test method does not apply to vessels in cryogenic service.

1.4 The AE measurements are used to detect and locate emission sources. Other nondestructive test (NDT) methods must be used to evaluate the significance of AE sources. Procedures for other NDT techniques are beyond the scope of this test method. See Note 1.

NOTE 1 — Shear wave, angle beam ultrasonic inspection is commonly used to establish circumferential position and dimensions of flaws that produce AE.

1.5 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements are given in Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings

E 543 Practice for Evaluating Agencies That Perform Nondestructive Testing

E 650 Guide for Mounting Piezoelectric Acoustic Emission Sensors

E 976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response

E 1316 Terminology for Nondestructive Examinations

2.2 *ASNT Standards:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *Military Standard:*

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification

2.4 *Code of Federal Regulations:*

Section 49, Code of Federal Regulations, Hazardous Materials Regulations of the Department of Transportation, Paragraphs 173.34, 173.301, 178.36, 178.37, and 178.45

2.5 *Compressed Gas Association Standard:*

Pamphlet C-5 Service Life, Seamless High Pressure Cylinders

3. Terminology

3.1 *Definitions* — See Terminology E 1316 for general terminology applicable to this test method.

3.2 *Descriptions of Terms Specific to This Standard:*

3.2.1 *fracture critical flaw* — a flaw that is large enough to exhibit unstable growth at service conditions.

3.2.2 *marked service pressure* — pressure for which a vessel is rated. Normally this value is stamped on the vessel.

3.2.3 *normal fill pressure* — level to which a vessel is pressurized. This may be greater, or may be less, than *marked service pressure.*

4. Summary of Test Method

4.1 The AE sensors are mounted on a vessel, and emission is monitored while the vessel is pressurized above normal fill pressure.

4.2 Sensors are mounted at each end of the vessel and are connected to an acoustic emission signal processor. The signal processor uses measured times of arrival of emission bursts to determine linear location of emission sources. If measured emission exceeds a prescribed level (that is, specific locations produce enough events), then such locations receive secondary (for example, ultrasonic) inspection.

4.3 Secondary inspection establishes presence of flaws and measures flaw dimensions.

4.4 If flaw depth exceeds a prescribed limit (that is, a conservative limit that is based on construction material, wall thickness, fatigue crack growth estimates, and fracture critical flaw depth calculations), then the vessel must be removed from service.

5. Significance and Use

5.1 Because of safety considerations, regulatory agencies (for example, U.S. Department of Transportation) require periodic tests of vessels used in transportation of industrial gases (see Section 49, Code of Federal Regulations). The AE testing has become accepted as an alternative to the common hydrostatic proof test. In the common hydrostatic test, volumetric expansion of vessels is measured.

5.2 An AE test should not be used for a period of one year after a common hydrostatic test. See Note 2.

NOTE 2 — The Kaiser effect relates to decreased emission that is expected during a second pressurization. Common hydrostatic tests use a relatively high test pressure (167% of normal service pressure). (See Section 49, Code of Federal Regulations.) If an AE test is performed too soon after such a pressurization, the AE results will be insensitive to a lower test pressure (that is, the lower pressure that is associated with an AE test).

5.3 *Pressurization:*

5.3.1 General practice in the gas industry is to use low pressurization rates. This practice promotes safety and reduces equipment investment. The AE tests should be performed with pressurization rates that allow vessel deformation to be in equilibrium with the applied load. Typical current practice is to use rates that approximate 500 psi/h (3.45 MPa/h).

5.3.2 Gas compressors heat the pressurizing medium. After pressurization, vessel pressure may decay as gas temperature equilibrates with ambient conditions.

5.3.3 Emission from flaws is caused by flaw growth and secondary sources (for example, crack surface contact and contained mill scale). Secondary sources can produce emission throughout vessel pressurization.

5.3.4 When pressure within a vessel is low, and gas is the pressurizing medium, flow velocities are relatively high. Flowing gas (turbulence) and impact by entrained particles can produce measurable emission. Considering this, acquisition of AE data may commence at some pressure greater than starting pressure (for example, $\frac{1}{3}$ of maximum test pressure).

5.3.5 *Maximum Test Pressure* — Serious flaws usually produce more acoustic emission (that is, more events, events with higher peak amplitude) from secondary sources than from flaw growth. When vessels are pressurized, flaws produce emission at pressures less than normal fill pressure. A maximum test pressure that is 10% greater than normal fill pressure allows measurement of emission from secondary sources in flaws and from flaw growth.

5.3.6 *Pressurization Schedule* — Pressurization should proceed at rates that do not produce noise from the pressurizing medium and that allow vessel deformation to be in equilibrium with applied load. Pressure holds are not necessary; however, they may be useful for reasons other than measurement of AE.

5.4 Excess background noise may distort AE data or render them useless. Users must be aware of the following common sources of background noise: high gas-fill rate (measurable flow noise); mechanical contact with the vessel by objects; electromagnetic interference (EMI) and radio frequency interference (RFI) from nearby broadcasting facilities and from other sources; leaks at pipe or hose connections; and airborne sand particles, insects, or rain drops. This test method should

not be used if background noise cannot be eliminated or controlled.

6. Basis of Application

6.1 *Personnel Qualification* — The NDT personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, MIL-STD-410, or a similar document. The practice or standard used and its applicable revision shall be specified in the contractual agreement between the using parties.

6.2 *Qualification of Nondestructive Testing Agencies* — If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E 543. The applicable edition of Practice E 543 shall be specified in the contractual agreement.

6.3 *Time of Examination* — The time of examination shall be in accordance with 5.2 unless otherwise specified.

6.4 *Procedures and Techniques* — The procedures and techniques to be used shall be as described in this test method unless otherwise specified. Specific techniques may be specified in the contractual agreement.

6.5 *Extent of Examination* — The extent of examination shall be in accordance with 4.2 and 10.9 unless otherwise specified.

7. Apparatus

7.1 Essential features of the apparatus required for this test method are provided in Fig. 1. Full specifications are in Annex A1.

7.2 Couplant must be used to acoustically connect sensors to the vessel surface. Adhesives that have acceptable acoustic properties, and adhesives used in combination with traditional couplants, are acceptable.

7.3 Sensors may be held in place with magnets, adhesive tape, or other mechanical means.

7.4 The AE sensors are used to detect strain-induced stress waves produced by flaws. Sensors must be held in contact with the vessel wall to ensure adequate acoustic coupling.

7.5 A preamplifier may be enclosed in the sensor housing or in a separate enclosure. If a separate preamplifier is used, cable length, between sensor and preamp, must not exceed 6 ft (1.83 m).

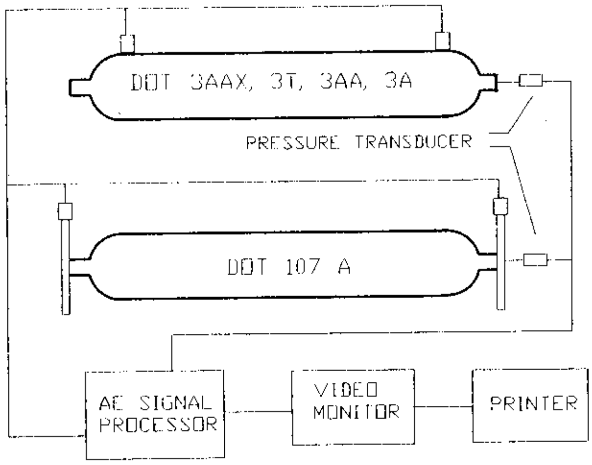


FIG. 1 ESSENTIAL FEATURES OF THE APPARATUS

7.6 Power/signal cable length (that is, cable between preamp and signal processor) shall not exceed 500 ft (152.4 m). See A1.5.

7.7 Signal processors are computerized instruments with independent channels that filter, measure, and convert analog information into digital form for display and permanent storage. A signal processor must have sufficient speed and capacity to independently process data from all sensors simultaneously. The signal processor should provide capability to filter data for replay. A printer should be used to provide hard copies of test results.

7.7.1 A video monitor should display processed test data in various formats. Display format may be selected by the equipment operator.

7.7.2 A data storage device, such as a floppy disk, may be used to provide data for replay or for archives.

7.7.3 Hard copy capability should be available from a graphics/line printer or equivalent device.

8. Safety Precautions

8.1 As in any pressure test of metal vessels, ambient temperature should not be below the ductile-brittle transition temperature of the pressure vessel construction material.

9. Calibration and Standardization

9.1 Annual calibration and verification of pressure transducer, AE sensors, preamplifiers (if applicable), signal processor (particularly the signal processor time reference), and AE electronic waveform generator should be performed. Equipment should be adjusted so that it conforms to equipment manufacturer's specifications. Instruments used for calibrations must have current accuracy certification that is traceable to the National Institute for Standards and Technology (NIST).

9.2 Routine electronic evaluations must be performed any time there is concern about signal processor performance. An AE electronic waveform generator should be used in making evaluations. Each signal processor channel must respond with peak amplitude reading within ±2 dBV of the electronic waveform generator output.

9.3 A system performance check must be conducted immediately before, and immediately after, each test. A performance check uses a mechanical device to induce stress waves into the vessel wall at a specified distance from each sensor. Induced stress waves stimulate a sensor in the same way as emission from a flaw. Performance checks verify performance of the entire system (including couplant).

9.3.1 The preferred technique for conducting a performance check is a pencil lead break. Lead should be broken on the vessel surface no more than 1.5 in. (3.8 cm) from the sensor. The 2H lead, 0.5-mm diameter, 3-mm long should be used (see Fig. 4 of Guide E 976).

10. Procedure

10.1 Visually examine accessible exterior surfaces of the vessel. Note observations in test report.

10.2 Isolate vessel to prevent contact with other vessels, hardware, and so forth. When the vessel cannot be completely isolated, indicate, in the test report, external sources which could have produced emission.

10.3 Connect fill hose and pressure transducer. Eliminate any leaks at connections.

10.4 Mount an AE sensor at each end of each tube. Use procedures specified in Guide E 650. Sensors must be at the same angular position and should be located at each end of the vessel so that the AE system can determine axial locations of sources in as much of the vessel as possible.

10.5 Adjust signal processor settings. See Appendix X1 for example.

10.6 Perform a system performance check at each sensor (see 9.3). Verify that peak amplitude is greater than a specified value (see Table X1.2). Verify that the AE system displays a correct location (see Note 3) for the mechanical device that is used to produce stress waves (see 9.4 and Table X1.2). Prior to pressurization, verify that there is no background noise above the signal processor threshold setting.

NOTE 3 — If desired location accuracy cannot be attained with sensors at two axial locations, then more sensors should be added to reduce sensor spacing.

10.7 Begin pressurizing the vessel. The pressurization rate shall be low enough that flow noise is not recorded.

10.8 Monitor the test by observing displays that show plots of AE events versus axial location. If unusual response (in the operator's judgment) is observed, interrupt pressurization and conduct an investigation.

10.9 Store all data on mass storage media. Stop the test when the pressure reaches 110% of normal fill pressure or 110% of marked service pressure (whichever is greater). The pressure shall be monitored with an accuracy of ±2% of the maximum test pressure.

10.9.1 *Examples:*

10.9.1.1 A tube trailer is normally filled to a gage pressure of 2640 psi (18.20 MPa). Pressurization shall stop at 2904 psi (20.02 MPa).

10.9.1.2 A gas cylinder is normally filled to a gage pressure of 613 psi (4.23 MPa). The marked service pressure is 2400 psi (16.55 MPa). Pressurization shall stop at 2640 psi (18.20 MPa).

10.10 Perform a system performance check at each sensor (see 9.3). Verify that peak amplitude is greater than a specified value (see Table X1.2).

10.11 Reduce pressure in vessel to normal fill pressure by bleeding excess gas to a receiver, or vent the vessel.

10.12 Raw AE data should be filtered to eliminate emission from nonstructural sources, for example, electronic noise.

10.13 Replay test data. Examine the location distribution plots (AE events versus axial location) for all vessels in the test.

10.14 Based on data replay, determine whether secondary examination (ultrasonic examination) is required.

(Ultrasonic examination should be performed in accordance with Practice A 388/A 388M.) Appendix X1 provides examples of such determinations.

11. Report

11.1 Prepare a written report from each test. Report the following information:

11.1.1 Name of the owner of the vessel and the vehicle number (if appropriate).

11.1.2 Test date and location.

11.1.3 Previous test date and previous maximum test pressure. See Note 4.

NOTE 4 — If the operator is aware of situations where the vessel was subject to pressures that exceeded normal fill pressure, these should be described in the report.

11.1.4 Any U.S. Department of Transportation (DOT) specification that applies to the vessel.

11.1.5 Any DOT exemption numbers that apply to the vessel.

11.1.6 Normal fill pressure and marked service pressure.

11.1.7 Pressurization medium.

11.1.8 Pressure at which data acquisition commenced.

11.1.9 Maximum test pressure.

11.1.10 Locations of AE sources that exceed acceptance criteria. Location shall include distance from end of vessel that bears the serial number (usually this is stamped in the vessel wall).

11.1.11 Signature of test operator.

11.1.12 Stacking chart that shows relative locations of vessels (if a multiple vessel array is tested).

11.1.13 Visual examination results.

11.1.14 AE test results, including events versus location plots for each vessel and cumulative events versus pressure plot for each vessel.

12. Precision and Bias

12.1 Location accuracy is influenced by factors that affect elastic wave propagation, by sensor coupling, and by signal processor settings.

12.2 It is possible to measure AE and produce AE source locations that cannot be verified by other NDT methods. If such emission are measured, and are produced by flaws, such flaws are small and are not of structural significance.

13. Keywords

13.1 acoustic emission; cylinders; flaws; gas pressure; seamless; steel

ANNEX

(Mandatory Information)

A1. INSTRUMENTATION SPECIFICATIONS

A1.1 Sensors

A1.1.1 The AE sensors shall have high sensitivity within the frequency band of 20 to 1200 kHz. Sensors may be broad band or resonant.

A1.1.2 Sensitivity shall be greater than −77 dBV (referred to 1 V/μbar, determined by face-to-face ultrasonic test) within the frequency range of intended use.

A1.1.3 Sensitivity within the range of intended use shall not vary more than 3 dB over the intended range of temperatures in which sensors are used.

A1.1.4 Sensors shall be shielded against electromagnetic interference through proper design practice or differential (anticoincidence) element design, or both.

A1.1.5 Sensors shall be electrically isolated from conductive surfaces by means of a shoe (a wear plate).

A1.2 Signal Cable

A1.2.1 The sensor signal cable which connects sensor and preamplifier shall not sensor output more than 3 dB [6 ft (1.83 m) is a typical maximum length]. Integral preamplifier sensors meet this requirement. They have inherently short, internal, signal cables.

A1.2.2 Signal cable shall be shielded against electromagnetic interference. Standard coaxial cable is generally adequate.

A1.3 Couplant

A1.3.1 A couplant shall provide adequate ultrasonic coupling efficiency throughout the test.

A1.3.2 The couplant must be temperature stable over the temperature range intended for use.

A1.3.3 Adhesives may be used if they satisfy ultrasonic coupling efficiency and temperature stability requirements.

A1.4 Preamplifier

A1.4.1 The preamplifier shall have noise level no greater than 7 μV rms (referred to a shorted input) within the bandpass range.

A1.4.2 The preamplifier gain shall vary no more than ±1 dB within the frequency band and temperature range of use.

A1.4.3 The preamplifier shall be shielded from electromagnetic interference.

A1.4.4 The preamplifiers of differential design shall have a minimum of 40-dB common mode rejection.

A1.4.5 The preamplifier shall include a bandpass filter with a minimum of 24-dB/octave signal attenuation above and below the 100 to 300-kHz frequency band.

A1.5 Power/Signal Cable

A1.5.1 The power/signal cables provide power to preamplifiers, and conduct amplified signals to the main processor. These shall be shielded against electromagnetic interference. Signal loss shall be less than 1 dB/100 ft (30.48 m) of cable length. Standard coaxial cable is generally adequate. Signal loss from a power/signal cable shall be no greater than 3 dB.

A1.6 Power Supply

A1.6.1 A stable, grounded, power supply that meets the signal processor manufacturer's specification shall be used.

A1.7 Signal Processor

A1.7.1 The electronic circuitry gain shall be stable within ±2 dB in the temperature range from 40 to 100°F (4.4 to 37.8°C).

A1.7.2 Threshold shall be accurate within ±2 dB.

A1.7.3 Measured AE parameters shall include: threshold crossing counts, peak amplitude, arrival time, rise time, and duration for each hit. Also, vessel internal pressure shall be measured.

A1.7.4 The counter circuit shall count threshold crossings within an accuracy of ±5% of true counts.

A1.7.5 Peak amplitude shall be accurate within ±2 dBV.

A1.7.6 Arrival time at each channel shall be accurate to within ±1.0 μs.

A1.7.7 Duration shall be accurate to within ±10 μs.

A1.7.8 Threshold shall be accurate to within ±1 dB.

A1.7.9 Arrival time shall be accurate to 0.5 μs.

A1.7.10 Rise time shall be accurate to ±10 μs.

A1.7.11 Parametric voltage readings from pressure transducers shall be accurate to within ±5% of the marked service pressure.

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE INSTRUMENT SETTINGS AND REJECTION CRITERIA

X1.1 A database and rejection criteria are established for some DOT specified vessels. These have been described in the NDT Handbook. More recent criteria are described in this section. Some vessel types, typical dimensions, and service pressures are listed in Table X1.1.

X1.2 Criteria for determining the need for secondary inspection were established while working with AE equipment with setup conditions listed in Table X1.2.

X1.3 Need for secondary inspection is based on examination of location distribution plots (that is, plots of AE events versus axial location) after AE data acquisition is completed.

X1.3.1 *Cylindrical Portion of Vessel* — The DOT 3AAX and 3T 3AA and 107A tubes are currently retested with this AE test method. For 3AAX and 3T and 3AA tubes, if five or more AE events occur within an 8-in. (20.3-cm) axial distance, on the cylindrical portion of a tube, then that part of the tube must be inspected with a secondary NDT method (for example, ultrasonic inspection). Any flaw that is detected must be precisely located, and flaw dimensions must be determined.

X1.3.2 *Ends of Vessel* — For DOT 3AAX and 3T and 3AA tubes, if five or more AE events are measured outboard of a sensor, each of these events is detected by both sensors, and the peak amplitude at the "first hit" sensor is 43 dBV or more, then the end of the tube at the "first hit sensor" (that is, the sensor with five or more first hits) must be inspected. Any flaw that is detected must be precisely located, and flaw dimensions must be determined using secondary NDT method (for example, ultrasonic inspection).

X1.3.3 The DOT 107A tubes are tested with sensors mounted on the end flanges. If five or more AE events occur within 8-in. (20.3-cm) axial distance on the cylindrical portion or end of the tube, then that part of the tube must be inspected with a secondary NDT method (for example, ultrasonic inspection). Any flaw that is detected must be precisely located, and flaw dimensions must be determined.

X1.4 *Rejection Criterion:*

X1.4.1 Vessels that contain flaws that are large enough to be "fracture critical flaws," or that contain flaws large enough to grow to fracture critical size before another retest is performed, shall be removed from service.

X1.4.2 "Fracture critical" flaw dimensions are based upon fracture mechanics analysis of a vessel using strength properties that correspond to materials of construction.

X1.4.3 Analyses of DOT 3AAX and 3T tubes are described by Blackburn and Rana. Fracture critical flaw depths were calculated, and fatigue crack growth (under worst case conditions) was estimated. Flaw depths that could grow to half the fracture critical size were judged too large. They should not remain in service. Based upon this conservative approach, DOT Specification 3AAX and 3T tubes with maximum flaw depths of 0.10 in. (2.54 mm), or more, should be permanently removed from service.

X1.4.3.1 The DOT 3AAX and 3T cylinders have been evaluated by Blackburn and Rana. The maximum allowable flaw depth was calculated to be 0.10 in. (2.54 mm).

TABLE X1.1
SPECIFIED CYLINDERS, TYPICAL DIMENSIONS, AND SERVICE PRESSURES

Specification	DOT 3AAX	DOT 3T	DOT 3A	DOT 3AA	DOT 107A
Outside diameter, in. (cm)	22 (55)	22 (56)	9.63 (25)	9.63 (25)	18 (46)
Nominal wall thickness, in. (cm)	0.54 (1.37)	0.42 (1.07)	0.31 (0.79)	0.25 (0.64)	0.75 or 0.86 (1.9 or 2.2)
Length, ft (m)	18 to 40 (0.5 to 12)		12 to 32 (4 to 10)		33 (10)
Typical service pressure, psi (MPa)	2400 (16.6)				2600 or 3300 (18 or 23)
Typical fill pressure, psi (MPa)	600 to 3000 (14.14 to 20.68)				2600 to 3300
Alternate retest method	hydrostatic test, at 1.67 times marked service pressure every five years with volumetric expansion measurement				

TABLE X1.2
ACOUSTIC EMISSION EQUIPMENT, CHARACTERISTICS, AND SETUP CONDITIONS

Sensor sensitivity	−77 dBV ref. 1V/μbar, at ~150 kHz
Couplant	silicone grease
Preamplifier gain	40 dB (×100)
Preamplifier filter	100 to 300-kHz bandpass
Power/signal cable length	<500 ft (152.4 m)
Signal processor threshold	32 dBV (for example, 1 uV = 0 dBV at preamplifier input)
Signal processor filter	100 to 300-kHz bandpass
Dead time	10 ms
Background noise	<27 dBV (for example, 1 uV = 0 dBV at preamplifier input)
Sensitivity check	>80 dBV (for example, 1 uV = 0 dBV at preamplifier input)

X1.4.3.2 The DOT 3AA and 3A cylinders were evaluated by Blackburn. Maximum allowable depths were calculated and 0.06 in. (1.524 mm) was specified for both specifications.

X1.4.3.3 The DOT 107A cylinders have been evaluated by Toughiry. The maximum flaw depth was calculated to be 0.150 in. (3.81 mm).

ARTICLE 30 TERMINOLOGY FOR NONDESTRUCTIVE EXAMINATIONS STANDARD

01

01 # STANDARD TERMINOLOGY FOR NONDESTRUCTIVE EXAMINATIONS

SE-1316

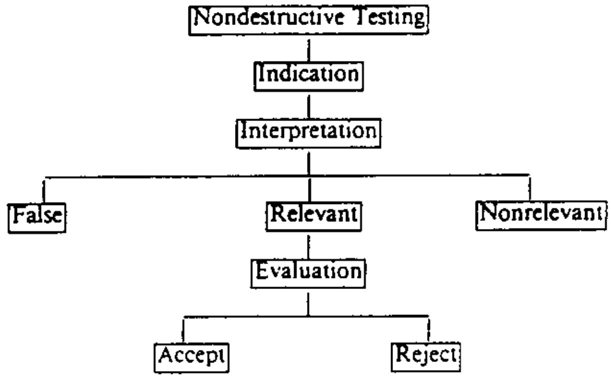
(Identical with ASTM E 1316-99 except for editorial differences)

1. Scope

1.1 This Standard defines the terminology used in the standards prepared by the E-7 Committee on Nondestructive Testing. These nondestructive testing (NDT) methods include: acoustic emission, electromagnetic testing, gamma- and X-radiology, leak testing, liquid penetrant examination, magnetic particle examination, neutron radiology and gaging, ultrasonic examination, and other technical methods.

1.2 Section 4 defines terms that are common to multiple NDT methods, and the subsequent sections define terms pertaining to specific NDT methods. An alphabetical list of the terms defined in this Standard is given in Appendix Xl, which also identifies the section in which each term is defined.

1.3 As shown on the chart below, when nondestructive testing produces an indication, the indication is subject to interpretation as false, nonrelevant, or relevant. If it has been interpreted as relevant, the necessary subsequent evaluation will result in the decision to accept or reject the material. With the exception of *accept* and *reject*, which retain the meaning found in most dictionaries, all the words used in the chart are defined in Section 4.



2. Referenced Documents

2.1 *ASTM Standards:*

E 127 Practice for Fabricating and Checking Aluminum Alloy Ultrasonic Standard Reference Blocks

E 215 Practice for Standardizing Equipment for Electromagnetic Examination of Seamless Aluminum-Alloy Tube

E 494 Practice for Measuring Ultrasonic Velocity in Materials

E 566 Practice for Electromagnetic (Eddy-Current) Sorting of Ferrous Metals

E 664 Practice for Measurement of the Apparent Attenuation of Longitudinal Ultrasonic Waves by Immersion Method

E 750 Practice for Characterizing Acoustic Emission Instrumentation

E 804 Practice for Calibration of the Ultrasonic Test System by Extrapolation Between Flat-Bottom Hole Sizes

E 1033 Practice for Electromagnetic (Eddy-Current) Examination of Type F- Continuously Welded (CW) Ferromagnetic Pipe and Tubing Above the Curie Temperature

E 1067 Practice for Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin (FRP) Tanks/Vessels

E 1118 Practice for Acoustic Emission Examination of Reinforced Thermosetting Resin Pipe (RTRP)

E 1213 Test Method for Minimum Resolvable Temperature Difference for Thermal Imaging Systems

3. Significance and Use

3.1 The terms found in this proposed standard are intended to be used uniformly and consistently in all nondestructive testing standards. The purpose of this standard is to promote a clear understanding and interpretation of the NDT standards in which they are used.

4. Common NDT Terms

acceptable quality level — the maximum percent defective or the maximum number of units defective per hundred units that, for the purpose of sampling test, can be considered satisfactory as a process average

calibration, instrument — the comparison of an instrument with, or the adjustment of an instrument to, a known reference(s) often traceable to the National Institute of Standards and Technology (NIST). (See also *standardization, instrument.*)

defect — one or more flaws whose aggregate size, shape, orientation, location, or properties do not meet specified acceptance criteria and are rejectable

discontinuity — a lack of continuity or cohesion; an intentional or unintentional interruption in the physical structure or configuration of a material or component

evaluation — a review, following interpretation of the indications noted, to determine whether they meet specified acceptance criteria

false indication — an NDT indication that is interpreted to be caused by a condition other than a discontinuity or imperfection

flaw — an imperfection or discontinuity that may be detectable by nondestructive testing and is not necessarily rejectable

flaw characterization — the process of quantifying the size, shape, orientation, location, growth, or other properties, of a flaw based on NDT response

imperfection — a depature of a quality characteristic from its intended condition

indication — the response or evidence from a nondestructive examination

DISCUSSION — An indication is determined by interpretation to be relevant, nonrelevant, or false.

interpretation — the determination of whether indications are relevant or nonrelevant

interpretation, n — the determination of whether indications are relevant, nonrelevant, or false.

Nondestructive Testing (NDT) — the development and application of technical methods to examine materials or components in ways that do not impair future usefulness and serviceability in order to detect, locate, measure, and evaluate flaws; to assess integrity, properties, and composition; and to measure geometrical characteristics

Nondestructive Evaluation — see *Nondestructive Testing*

Nondestructive Examination — see *Nondestructive Testing*

Nondestructive Inspection — see *Nondestructive Testing*

nonrelevant indication — an NDT indication that is caused by a condition or type of discontinuity that is not rejectable. False indications are nonrelevant.

relevant indication — an NDT indication that is caused by a condition or type of discontinuity that requires evaluation

standardization, instrument — the adjustment of an instrument, prior to use, to an arbitrary reference value. (See also *calibration, instrument.*)

5. Acoustic Emission (E 750, E 1067, and E 1118)

acoustic emission (AE) — the class of phenomena whereby transient elastic waves are generated by the rapid release of energy from localized sources within a material, or the transient waves so generated. Acoustic emission is the recommended term for general use. Other terms that have been used in AE literature include: *(1)* stress wave emission; *(2)* microseismic activity; and *(3)* emission or acoustic emission with other qualifying modifiers.

acoustic emission channel — see *channel, acoustic emission*

acoustic emission count (emission count) (N) — see *count, acoustic emission*

acoustic emission count rate — see *count rate, acoustic emission (emission rate or count rate) (N)*

acoustic emission event — see *event, acoustic emission*

acoustic emission event energy — see *energy, acoustic event*

acoustic emission sensor — see *sensor, acoustic emission*

acoustic emission signal amplitude — see *signal amplitude, acoustic emission*

acoustic emission signal (emission signal) — see *signal, acoustic emission*

acoustic emission signature (signature) — see *signature, acoustic emission*

acoustic emission transducer — see *sensor, acoustic emission*

acoustic emission waveguide — see *waveguide, acoustic emission*

acousto-ultrasonics (AU) — a nondestructive examination method that uses induced stress waves to detect and assess diffuse defect states, damage conditions, and variations of mechanical properties of a test structure. The AU method combines aspects of acoustic emission (AE) signal analysis with ultrasonic materials characterization techniques.

adaptive location — source location by iterative use of simulated sources in combination with computed location

AE activity — the presence of acoustic emission during a test

AE rms — the rectified, time averaged AE signal, measured on a linear scale and reported in volts

AE signal duration — the time between AE signal start and AE signal end

AE signal end — the recognized termination of an AE signal, usually defined as the last crossing of the threshold by that signal

AE signal generator — a device which can repeatedly induce a specified transient signal into an AE instrument

AE signal rise time — the time between AE signal start and the peak amplitude of that AE signal

AE signal start — the beginning of an AE signal as recognized by the system processor, usually defined by an amplitude excursion exceeding threshold

array — a group of two or more AE sensors positioned on a structure for the purposes of detecting and locating sources. The sources would normally be within the array.

arrival time interval (Δt_{ij}) — see *interval, arrival time*

attenuation — the decrease in AE amplitude per unit distance, normally expressed in dB per unit length

average signal level, n — the rectified, time averaged AE logarithmic signal, measured on the AE amplitude logarithmic scale and reported in dB_{ae} units (where 0 dB_{ae} refers to 1 μV at the preamplifier input)

burst emission — see *emission, burst*

channel, acoustic emission — an assembly of a sensor, preamplifier, or impedance matching transformer, filters, secondary amplifier, or other instrumentation as needed, connecting cables, and detector or processor

NOTE 1 — A channel for examining fiberglass reinforced plastic (FRP) may utilize more than one sensor with associated electronics. Channels may be processed independently or in predetermined groups having similar sensitivity and frequency characteristics.

continuous emission — see *emission, continuous*

count, acoustic emission (emission count) (N) — the number of times the acoustic emission signal exceeds a preset threshold during any selected portion of a test

count, event (N_e) — the number obtained by counting each discerned acoustic emission event once

count rate, acoustic emission (emission rate or count rate)(N) — the time rate at which emission counts occur

count ring-down — see *count, acoustic emission,* the preferred term

couplant — a material used at the structure-to-sensor interface to improve the transmission of acoustic energy across the interface during acoustic emission monitoring

cumulative (acoustic emission) amplitude distribution F(V) — see *distribution, amplitude, cumulative*

cumulative (acoustic emission) threshold crossing distribution $F_t(V)$ — see *distribution, threshold crossing, cumulative*

dB_{AE} — a logarithmic measure of acoustic emission signal amplitude, referenced to 1 μV.

$$\text{Signal peak amplitude } (dB_{AE}) = 20 \log_{10}(A_1/A_0)$$

where:

A_0 = 1 μV at the sensor output (before amplification)
A_1 = peak voltage of the measured acoustic emission signal

Acoustic Emission Reference Scale:

dB_{AE} Value	Voltage at Sensor Output
0	1 μV
20	10 μV
40	100 μV
60	1 mV
80	10 mV
100	100 mV

dead time — any interval during data acquisition when the instrument or system is unable to accept new data for any reason (E 750)

differential (acoustic emission) amplitude distribution f(V) — see *distribution, differential (acoustic emission) amplitude f(V)*

differential (acoustic emission) threshold crossing distribution $f_t(V)$ — see *distribution, differential (acoustic emission) threshold crossing*

distribution, amplitude, cumulative (acoustic emission) F(V) — the number of acoustic emission events with signals that exceed an arbitrary amplitude as a function of amplitude *V*

distribution, threshold crossing, cumulative (acoustic emission) $F_t(V)$ — the number of times the acoustic emission signal exceeds an arbitrary threshold as a function of the threshold voltage (V)

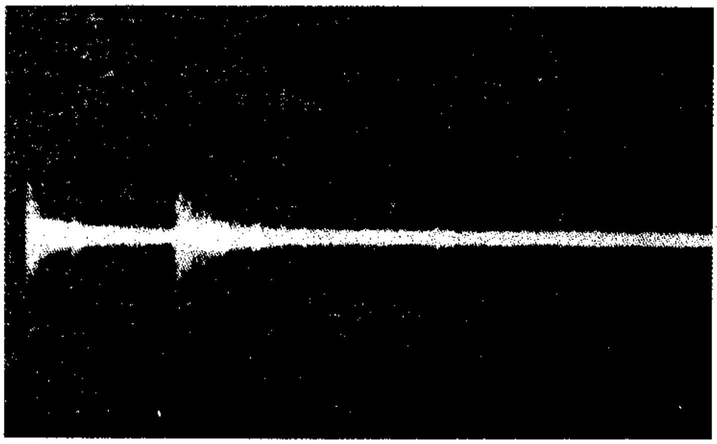


FIG. 1 BURST EMISSION ON A CONTINUOUS EMISSION BACKGROUND (SWEEP RATE — 5 ms/cm)

distribution, differential (acoustic emission) amplitude f(V) — the number of acoustic emission events with signal amplitudes between amplitudes of V and $V + \Delta V$ as a function of the amplitude V. $f(V)$ is the absolute value of the derivative of the cumulative amplitude distribution $F(V)$.

distribution, differential (acoustic emission) threshold crossing $f_t(V)$ — the number of times the acoustic emission signal waveform has a peak between thresholds V and $V + \Delta V$ as a function of the threshold V. $f_t(V)$ is the absolute value of the derivative of the cumulative threshold crossing distribution $F_t(V)$.

distribution, logarithmic (acoustic emission) amplitude g(V) — the number of acoustic emission events with signal amplitudes between V and αV (where α is a constant multiplier) as a function of the amplitude. This is a variant of the differential amplitude distribution, appropriate for logarithmically windowed data.

dynamic range — the difference, in decibels, between the overload level and the minimum signal level (usually fixed by one or more of the noise levels, low-level distortion, interference, or resolution level) in a system or sensor

effective velocity — velocity calculated on the basis of arrival times and propagation distances determined by artificial AE generation; used for computed location

emission, burst — a qualitative description of the discrete signal related to an individual emission event occurring within the material

NOTE 2 — Use of the term burst emission is recommended only for describing the qualitative appearance of emission signals. Figure 1 shows an oscilloscope trace of burst emission signals on a background of continuous emission.

emission, continuous — a qualitative description of the sustained signal level produced by rapidly occurring acoustic emission from structural sources, leaks, or both

NOTE 3 — Use of the term *continuous emission* is recommended only for describing the qualitative appearance of emission signals. Figures 2 and 3 show oscilloscope traces of continuous emission signals at two different sweep rates.

energy, acoustic emission event — the total elastic energy released by an emission event

energy, acoustic emission signal — the energy contained in a detected acoustic emission burst signal, with units usually reported in joules and values which can be expressed in logarithmic form (dB, decibels)

evaluation threshold — a threshold value used for analysis of the examination data. Data may be recorded with a *system examination threshold* lower than the *evaluation threshold.* For analysis purposes, dependence of measured data on the *system examination threshold* must be taken into consideration.

event, acoustic emission (emission event) — a local material change giving rise to acoustic emission

event count (Ne) — see *count, event*

event count rate (Ne) — see *rate, event count*

examination area — that portion of a structure being monitored with acoustic emission

examination region — that portion of the test article evaluated using acoustic emission technology

Felicity effect — the presence of acoustic emission, detectable at a fixed predetermined sensitivity level at stress levels below those previously applied (E 1067)

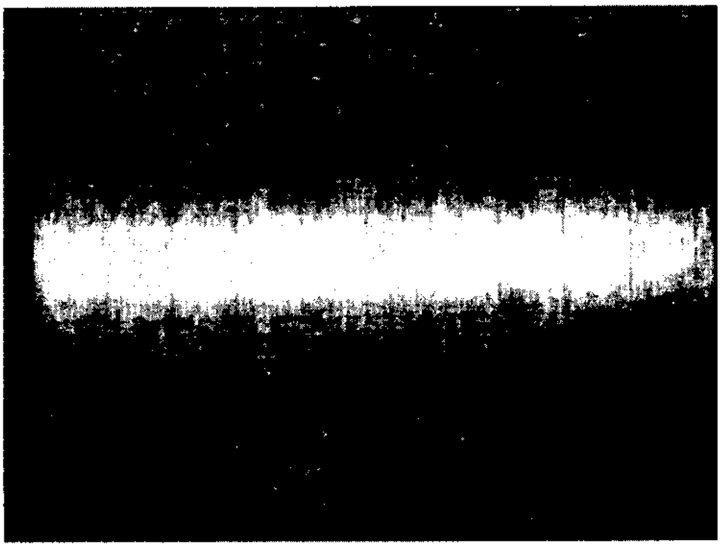


FIG. 2 CONTINUOUS EMISSION (SWEEP RATE — 5 ms/cm)

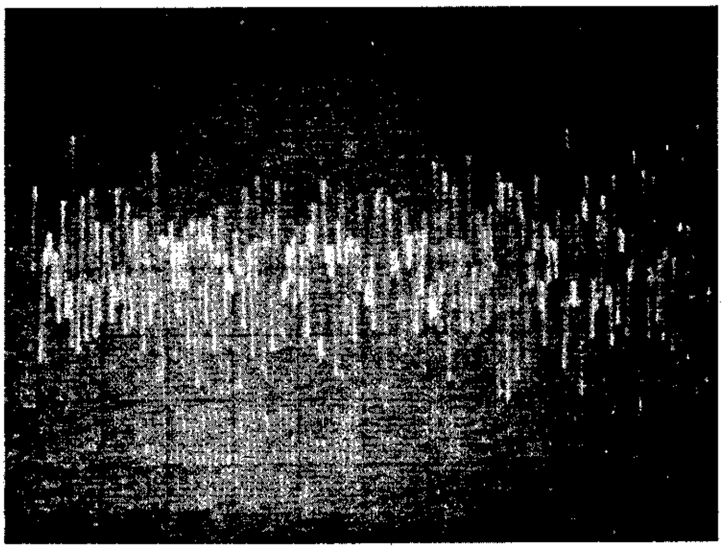


FIG. 3 CONTINUOUS EMISSION (SWEEP RATE — 0.1 ms/cm)

Felicity effect — the presence of detectable acoustic emission at a fixed predetermined sensitivity level at stress levels below those previously applied

Felicity ratio — the ratio of the stress at which the Felicity effect occurs to the previously applied maximum stress (E 1067, E 1118)

NOTE 4 — The fixed sensitivity level will usually be the same as was used for the previous loading or test. (E 1118)

instrumentation dead time — see *dead time, instrumentation*

first hit location — a zone location method defined by which channel among a group of channels first detects the signal

floating threshold — any threshold with amplitude established by a time average measure of the input signal (E 750)

hit — the detection and measurement of an AE signal on a channel

interval, arrival time (Δt_{ij}) — the time interval between the detected arrivals of an acoustic emission wave at the *ith* and *jth* sensors of a sensor array

Kaiser effect — the absence of detectable acoustic emission at a fixed sensitivity level, until previously applied stress levels are exceeded

location accuracy — a value determined by comparison of the actual position of an AE source (or simulated AE source) to the computed location

location, cluster — a location technique based upon a specified amount of AE activity located within a specified area, for example: 5 events within 12 linear in., or 12 sq. in.

location, computed — a source location method based on algorithmic analysis of the difference in arrival times among sensors

DISCUSSION — Several approaches to computed location are used, including linear location, planar location, three dimensional location, and adaptive location.

(a) *linear location* — one dimensional source location requiring two or more channels.

(b) *planar location* — two dimensional source location requiring three or more channels.

(c) *3D location* — three dimensional source location requiring five or more channels.

(d) *adaptive location* — source location by iterative use of simulated sources in combination with computed location.

location, continuous AE signal — a method of location based on continuous AE signals, as opposed to hit or difference in arrival time location methods

DISCUSSION — This type of location is commonly used in leak location due to the presence of continuous emission. Some common types of continuous signal location methods include signal attentuation and correlation analysis methods.

(a) *signal attenuation-based source location* — a source location method that relies on the attenuation versus distance phenomenon of AE signals. By monitoring the AE signal magnitudes of the continuous signal at various points along the object, the source can be determined based on the highest magnitude or by interpolation or extrapolation of multiple readings.

(b) *correlation-based source location* — a source location method that compares the changing AE signal levels (usually waveform based amplitude analysis) at two or more points surrounding the source and determines the time displacement of these signals. The time displacement data can be used with conventional hit based location techniques to arrive at a solution for the source site.

location, source — any of several methods of evaluating AE data to determine the position on the structure from which the AE originated. Several approaches to source location are used, including zone location, computed location, and continuous location

location, zone, n — any of several techniques for determining the general region of an acoustic emission source (for example, total AE counts, energy, hits, and so forth)

DISCUSSION — Several approaches to zone location are used, including independent channel zone location, first hit zone location, and arrival sequence zone location.

(a) *independent channel zone location, n* — a zone location technique that compares the gross amount of activity from each channel.

(b) *first-hit zone location, n* — a zone location technique that compares only activity from the channel first detecting the AE event.

(c) *arrival sequence zone location, n* — a zone location technique that compares the order of arrival among sensors.

logarithmic (acoustic emission) amplitude distribution g(V) — see *distribution, logarithmic (acoustic emission) amplitude*

overload recovery time — an interval of nonlinear operation of an instrument caused by a signal with amplitude in excess of the instrument's linear operating range

pressure, design — pressure used in design to determine the required minimum thickness and minimum mechanical properties

processing capacity — the number of hits that can be processed at the processing speed before the system must interrupt data collection to clear buffers or otherwise prepare for accepting additional data

processing speed — the sustained rate (hits/s), as a function of the parameter set and number of active channels, at which AE signals can be continuously processed by a system without interruption for data transport

rate, event count (Ne) — the time rate of the event count

rearm delay time — see *time, rearm delay*

ring-down count — see *count, acoustic emission, the preferred term*

sensor, acoustic emission — a detection device, generally piezoelectric, that transforms the particle motion produced by an elastic wave into an electrical signal

signal, acoustic emission (emission signal) — an electrical signal obtained by detection of one or more acoustic emission events

signal amplitude, acoustic emission — the peak voltage of the largest excursion attained by the signal waveform from an emission event

signal overload level — that level above which operation ceases to be satisfactory as a result of signal distortion, overheating, or damage

signal overload point — the maximum input signal amplitude at which the ratio of output to input is observed to remain within a prescribed linear operating range

signature, acoustic emission (signature) — a characteristic set of reproducible attributes of acoustic emission signals associated with a specific test article as observed with a particular instrumentation system under specified test conditions

stimulation — the application of a stimulus such as force, pressure, heat, etc., to a test article to cause activation of acoustic emission sources

system examination threshold — the electronic instrument threshold (see *evaluation threshold*) at which data will be detected

transducers, acoustic emission — see *sensor, acoustic emission*

voltage threshold — a voltage level on an electronic comparator such that signals with amplitudes larger than this level will be recognized. The voltage threshold may be user adjustable, fixed, or automatic floating. (E 750)

waveguide, acoustic emission — a device that couples elastic energy from a structure or other test object to a remotely mounted sensor during AE monitoring. An example of an acoustic emission waveguide would be a solid wire or rod that is coupled at one end to a monitored structure, and to a sensor at the other end.

6. Electromagnetic Testing (E 215, E 243, E 566, E 1033)

absolute coil — a coil (or coils) that respond(s) to the total detected electric or magnetic properties, or both, of a part or section of the test part without comparison to another section of the part or to another part (E 566)

absolute measurements — in electromagnetic testing, measurements made without a direct reference using an absolute coil in contrast to differential and comparative measurements (see also *absolute coil*)

absolute readout — in electromagnetic testing, the signal output of an absolute coil (see also *absolute coil*)

absolute system — a system that uses a coil assembly and associated electronics to measure the total electromagnetic properties of a test part without direct comparison to another section of the part or to another part (see *absolute coil*) (E 566)

acceptance level — a test level above or below which test specimens are acceptable in contrast to rejection level

acceptance limits — test levels used in electromagnetic inspection that establish the group into which a material under test belongs

acceptance standard — in tubing inspection, a tube used to establish the acceptance level with artificial discontinuities as specified in the applicable product standard

acceptance standard — a tube with artificial discontinuities specified in the applicable product standard used to establish the acceptance level (E 215)

amplitude distortion — same as *harmonic distortion*

amplitude response — that property of a test system whereby the amplitude of the detected signal is measured without regard to phase (see also *harmonic analysis and phase analysis*)

annular coil clearance — the mean radial distance between adjacent coil assembly and test part surface in electromagnetic encircling coil examination

annular coils — see *encircling coils*

artificial discontinuity — reference discontinuities, such as holes, grooves, or notches that are introduced into a reference standard to provide accurately reproducible sensitivity levels for electromagnetic test equipment

band pass filter — a wave filter having a single transmission band, neither of the cut-off frequencies being zero or infinity

bobbin coil — see *ID coil*

bucking coils — same as *differential coils*

circumferential coils — see *encircling coils*

coil, absolute — see *absolute coil*

coil, reference — see *reference coil*

coil size — the dimension of a coil, for example, length or diameter

coil spacing — in electromagnetic testing, the axial distance between two encircling coils of a differential system

coil, test — in electromagnetic testing, the section of the probe or coil assembly that excites and/or detects the electromagnetic field in the material under test

comparative measurements — in electromagnetic testing, measurements made in which the unbalance in the system is measured using comparator coils in contrast to differential and absolute measurements. (See also *comparator coils.*)

comparative readout — in electromagnetic testing, the signal output of comparator coils. (See also *comparator coils.*)

comparative system — a system that uses coil assemblies and associated electronics to detect any electric or magnetic condition, or both, that is not common to the test specimen and the standard (see *comparator coils*) (E 566)

comparator coils — in electromagnetic testing, two or more coils electrically connected in series opposition but arranged so that there is no mutual induction (coupling) between them such that any electric or magnetic condition, or both, that is not common to the test specimen and the standard, will produce an unbalance in the system and thereby yield an indication

conductivity — the intrinsic property of a particular material to carry electric current; it is commonly expressed in percent IACS (International Annealed Copper Standard) or MS/m (Megasiemens/meter)

coupling — two electric circuits are said to be coupled to each other when they have an impedance in common so that a current in one causes a voltage in the other

cut-off level — same as *rejection level*

defect resolution — a property of a test system that enables the separation of indications due to defects in a test specimen that are located in close proximity to each other

depth of penetration — in electromagnetic testing, the depth at which the magnetic field strength or intensity of induced eddy currents has decreased to 37% of its surface value. The depth of penetration is an exponential function of the frequency of the signal and the conductivity and permeability of the material. Synonymous terms are *standard depth of penetration* and *skin depth.* (see also *skin effect*)

diamagnetic material — a material whose relative permeability is less than unity

NOTE 5 — The intrinsic induction Bi is oppositely directed to the applied magnetizing force *H*.

differential coils — two or more coils electrically connected in series opposition such that any electric or magnetic condition, or both, that is not common to the areas of a specimen being electromagnetically tested will produce an unbalance in the system and thereby yield an indication

differential measurements — in electromagnetic testing, measurements made in which the imbalance in the system is measured using differential coils in contrast to absolute and comparative measurements (see also *differential coils*)

differential readout — in electromagnetic testing, the signal output of differential coils (see also *differential coils*)

differential signal — in electromagnetic testing, an output signal that is proportional to the rate of change of the input signal

differential system — an electromagnetic testing system that uses coil assemblies and associated electronics to detect an electric or magnetic condition, or both, that is not common to the areas of the specimen being tested. (See also *differential coils.*)

eddy current — an electrical current caused to flow in a conductor by the time or space variation, or both, of an applied magnetic field

eddy current testing — a nondestructive testing method in which eddy current flow is induced in the test object. Changes in the flow caused by variations in the specimen are reflected into a nearby coil, coils, or Hall effect device for subsequent analysis by suitable instrumentation and techniques.

edge effect — in electromagnetic testing, the disturbance of the magnetic field and eddy currents due to the proximity of an abrupt change in specimen geometry (edge). This effect generally results in the masking of discontinuities within the affected region. (This effect is also termed the *end effect.*)

effective depth penetration (EDP) — in electromagnetic testing, for (a) thickness, the minimum depth beyond which a test system can no longer reliably detect a further increase in specimen thickness, or (b) defects, the limit for reliably detecting metallurgical or mechanical discontinuities by way of conventional continuous wave (CW) eddy current instrumentation and sensors. The EDP point is approximately three times the standard depth of penetration.

effective permeability — a hypothetical quantity that describes the magnetic permeability that is experienced under a given set of physical conditions such as a cylindrical test specimen in an encircling coil at a specific test frequency. This quantity may be different from the permeability of the particular metal being tested in that it takes into account such things as the

geometry of the part, the relative position of the encircling coil, and characteristics of the magnetic field.

electrical center — the center established by the electromagnetic field distribution within a test coil. A constant intensity signal, irrespective of the circumferential position of a discontinuity, is indicative of electrical centering. The electrical center may be different from the physical center of the test coil.

electromagnetic testing — a nondestructive test method for materials, including magnetic materials, that uses electromagnetic energy having frequencies less than those of visible light to yield information regarding the quality of testing material

encircling coils — in electromagnetic testing, coil(s) or coil assembly that surround(s) the part to be tested. Coils of this type are also referred to as annular, circumferential, or feed-through coils.

end effect — see *edge effect*

end effect — the loss in sensitivity to discontinuities located near the extreme ends of the tube as the ends of the tube enter or leave the test coil (E 215)

feed-through coils — see *encircling coils*

ferromagnetic material — a material that, in general, exhibits the phenomena of magnetic hysteresis and saturation, and whose permeability is dependent on the magnetizing force

fill factor — for internal probe electromagnetic testing, the ratio of the effective cross-sectional area of the primary internal probe coil to the cross-sectional area of the tube interior

fill factor — for encircling coil electromagnetic testing, the ratio of the cross-sectional area of the test specimen to the effective cross-sectional core area of the primary encircling coil (outside diameter of coil form, not inside diameter which is adjacent to specimen)

filter — a network that passes electromagnetic wave energy over a described range of frequencies and attenuates energy at all other frequencies

frequency — the number of cycles per second of alternating electric current induced into the tubular product. For eddy-current testing described herein, the frequency is normally 1 to 125 kHz, inclusive. (E 215)

gate — same as *rejection level*

harmonic analysis — an analytical technique whereby the amplitude or phase, or both, of the frequency components of a complex periodic signal is determined

harmonic distortion — nonlinear distortion characterized by the appearance in the output of harmonics other than the fundamental component when the input wave is sinusoidal

IACS — the International Annealed Copper Standard; an international standard of electrical conductivity

ID coil — a coil or coil assembly used for electromagnetic testing by insertion into the test piece as in the case of an inside probe for tubing. Coils of this type are also referred to as inside coils, inserted coils, or bobbin coils.

impedance — the total opposition that a circuit presents to the flow of an alternating current, specifically the complex quotient of voltage divided by current

impedance analysis — in electromagnetic testing, an analytical method that consists of correlating changes in the amplitude, phase, or quadrature components, or all of these, of a complex test signal voltage to the electromagnetic conditions within the test specimen

impedance plane diagram — a graphical representation of the locus of points, indicating the variations in the impedance of a test coil as a function of basic test parameters

incremental permeability — the ratio of the change in magnetic induction to the corresponding change in magnetizing force when the mean induction differs from zero

indications — eddy-current signals caused by any change from uniformity of a tube. These changes from uniformity affect the electrical characteristic of the tube but may not be detrimental to the end use of the product (E 215)

initial permeability — the slope of the induction curve at zero magnetizing force as the test specimen is being removed from a demagnetizing condition (slope at origin of BH curve before hysteresis is observed)

inserted coil — see *ID coil*

inside coil — see *ID coil*

lift-off effect — the effect observed in an electromagnetic test system output due to a change in magnetic coupling between a test specimen and a probe coil whenever the distance between them is varied

magnetic history — magnetic condition of a ferromagnetic part under test based on previous exposures to magnetic fields (E 566)

magnetic leakage flux — the excursion of magnetic lines of force from the surface of a test specimen

magnetic saturation — that degree of magnetization where a further increase in magnetizing force produces no significant increase in magnetic flux density (permeability) in a specimen

modulation analysis — an analytical method used in electromagnetic testing that separates responses due to various factors influencing the total magnetic field by

separating and interpreting, individually, frequencies or frequency bands in the modulation envelope of the (carrier frequency) signal

noise — in electromagnetic inspection, any nonrelevant signal that tends to interfere with the normal reception or processing of a desired flaw signal. It should be noted that such noise signals may be generated by inhomogeneities in the inspected part that are not detrimental to the end use of the part.

nonferromagnetic material — a material that is not magnetizable and hence, essentially not affected by magnetic fields. This would include paramagnetic materials and diamagnetic materials.

normal permeability — the ratio of the induction (when cyclically made to change symmetrically about zero) to the corresponding change in magnetizing force

off-line testing — eddy current tests conducted on equipment that includes the test coil and means to propel individual tubes under test through the coil at appropriate speeds and conditions

on-line testing — eddy current tests conducted on equipment that includes the test coil and means to propel tubes under test through the coil at appropriate speeds and conditions as an integral part of a continuous tube manufacturing sequence

optimum frequency — in electromagnetic testing, that frequency which provides the largest signal-to-noise ratio obtainable for the detection of an individual material property. Each property of a given material may have its own optimum frequency.

paramagnetic material — a material that has a relative permeability slightly greater than unity and that is practically independent of the magnetizing force

permeability, a-c — a generic term used to express various dynamic relationships between magnetic induction, B, and magnetizing force, H, for magnetic material subjected to a cyclic excitation by alternating or pulsating current. The values of a-c permeability obtained for a given material depend fundamentally upon the excursion limits of dynamic excitation and induction, the method and conditions of measurement, and also upon such factors as resistivity, thickness of laminations, frequency of excitation, etc.

NOTE 6 — The numerical value for any permeability is meaningless unless the corresponding B or H excitation level is specified. For incremental permeabilities not only must the corresponding d-c B or H excitation level be specified, but also the dynamic range (ΔB or ΔH).

permeability, d-c — permeability is a general term used to express relationships between magnetic induction, B, and magnetizing force, H, under various conditions of magnetic excitation. These relationships are either *(1)* absolute permeability, which in general is the quotient of a change in magnetic induction divided by the corresponding change in magnetizing force, or *(2)* relative permeability, which is the ratio of the absolute permeability to the magnetic constant (γ_m).

NOTE 7 — The magnetic constant γ_m is a scalar quantity differing in value and uniquely determined by each electromagnetic system of units. In the unrationalized cgs system γ_m is 1 gauss/oersted and the mksa rationalized system $\gamma_m = 4\pi \times 10^{-7}$ H/m.

NOTE 8 — Relative permeability is a pure number which is the same in all unit systems. The value and dimension of absolute permeability depends on the system of units employed.

NOTE 9 — For any ferromagnetic material, permeability is a function of the degree of magnetization. However, initial permeability, μ_0 and maximum permeability, μ_m are unique values for a given specimen under specified conditions.

NOTE 10 — Except for initial permeability, μ_0, a numerical value for any of the d-c permeabilities is meaningless unless the corresponding B or H excitation level is specified.

NOTE 11 — For the incremental permeabilities $\mu\Delta$ and $\mu\Delta i$, a numerical value is meaningless unless both the corresponding values of mean excitation level (B or H) and the excursion range (ΔB or ΔH) are specified.

phase analysis — an analytical technique that discriminates between variables in a part undergoing electromagnetic testing part by the different phase angle changes that these conditions produce in the test signal. See also *phase detection.*

phase angle — the angular equivalent of the time displacement between corresponding points on two sine waves of the same frequency

phase detection — the derivation of a signal whose amplitude is a function of the phase angle between two alternating currents, one of which is used as a reference

phase-sensitive system — a system whose output signal is dependent on the phase relationship between the voltage returned from a pickup or sensing coil and a reference voltage

phase shift — a change in the phase relationship between two alternating quantities of the same frequency

probe coil — in electromagnetic testing, a small coil or coil assembly that is placed on or near the surface of test objects

probe coil clearance — the perpendicular distance between adjacent surfaces of the probe and test part; also lift-off

recovery time — the time required for a test system to return to its original state after it has received a signal

reference coil — a coil or probe, which may be used in conjunction with the appropriate material, to electrically balance a comparative system

reference standard — a tube, plate or part with artificial discontinuities used for establishing the test sensitivity setting and for periodically checking and adjusting sensitivity setting as required [see also *standard* (1)] (E 215)

rejection level — the value established for a test signal above or below which test specimens are rejectable, or otherwise distinguished from the remaining specimens

selectivity — the characteristic of a test system that is a measure of the extent to which an instrument is capable of differentiating between the desired signal and disturbances of other frequencies or phases

sensitivity control — the control in the instrument that adjusts the amplifier gain, and is one of the factors that determines the capacity to detect discontinuities (E 215)

signal gradient — same as *differential readout*

signal-to-noise ratio — the ratio of values to signal (response containing relevant information) to that of noise (response containing nonrelevant information)

skin depth — see *depth of penetration*

skin effect — the phenomenon wherein the depth of penetration of electric currents into a conductor decreases as the frequency of the current is increased. At very high frequencies, the current flow is restricted to an extremely thin outer layer of the conductor. (See also *depth of penetration.*)

speed effect — the phenomenon in electromagnetic testing of which the evidence is a change in the signal voltage resulting from a change in the relative motion between the specimen and a test coil assembly

standard — *(1)* a physical reference used as a basis for comparison or calibration; *(2)* a concept that has been established by authority, custom, or agreement to serve as a model or rule in the measurement of quality or the establishment of a practice or procedure.

standard depth of penetration — see *depth of penetration*

standard depth of penetration (SDP) — the depth at which the eddy current density is reduced to approximately 37% of the density at the surface. Eddy-current testing is most effective when the wall thickness does not exceed the SDP or in heavier tube walls when discontinuities of interest are within one SDP (E 215)

test coil — the section of the coil assembly that examines the material under test in a comparative system; the coil used to examine the material in an absolute or differential comparative system (E 566)

test frequency — in electromagnetic testing, the number of complete cycles per unit time of the alternating current applied to the primary test coil

test quality level — see *rejection level*

three way sort — an electromagnetic sort based on a signal response from the material under test above or below two levels established by three or more calibration standards

threshold level — the setting of an instrument that causes it to register only those changes in response greater or less than a specified magnitude

threshold setting — the setting of the instrument that causes it to register only those changes in eddy-current response greater than a specified magnitude (E 215)

NOTE 12 — Sensitivity and threshold settings usually are indicated by arbitrary numbers on the control panel of the testing instrument. These numerical settings differ among instruments of different types. It is, therefore, not proper to translate a numerical setting on one instrument to that of another type. Even among instruments of the same design and from the same manufacturer, sensitivity and threshold settings may vary slightly when detecting the same discontinuity. Therefore, undue emphasis on the numerical value of sensitivity and threshold settings is not justified. (E 215)

transducer — an electromagnetic device for converting electrical energy into magnetic or mechanical energy and vice versa (E 1033)

two-way sort — an electromagnetic sort based on a signal response from the material under test above or below a level established by two or more calibration standards

wobble — in electromagnetic testing, an effect that produces variations in coil spacing (operational lift-off) due to lateral motion of the test specimen in passing through an encircling coil

7. Gamma- and X-Radiology

absorbed dose — the amount of energy imparted by ionizing radiation per unit mass of irradiated matter. Denoted by *rad*; 1 rad; = 0.01 j/kg. SI unit is *gray*; 1 gray = 1 j/kg.

absorbed dose rate — the absorbed dose per unit of time; rads/s. SI unit, grays/s.

absorption — the process whereby the incident particles or photons of radiation are reduced in number or energy as they pass through matter

accelerating potential — the difference in electric potential between the cathode and anode in an X-ray tube through which a charged particle is accelerated: usually expressed in units of kV or MV

activation — in neutron radiography, the process of causing a substance to become artificially radioactive by subjecting it to bombardment by neutrons or other particles

acute radiation syndrome — the immediate effects of a short term, whole body overexposure of a person to ionizing radiation. These effects include nausea and vomiting, malaise, increased temperature, and blood changes

alphanumeric — term pertaining to both numbers and alphabetical characters, typically used to designate a device capable of handling both types of characters

alpha particle — a positively charged particle emitted by certain radio-nuclides. It consists of two protons and two neutrons, and is identical to the nucleus of a helium atom

analog image — an image produced by a continuously variable physical process (for example, exposure of film)

analog to digital converter (a/d) — a device that changes an analog signal to a digital representation of the signal

anode — the positive electrode of a discharge tube. In an X-ray tube, the anode carries the target

anode current — the electrons passing from the cathode to the anode in an X-ray tube, minus the small loss incurred by the back scattered fraction

aperture — an opening in material, space, or time over which an element is considered to be active

array processor — a special purpose logical processing device that performs extremely fast mathematical operations on digital arrays

area of interest — the specific portion of the object image on the radiograph that is to be evaluated

artifact — spurious indication on a radiograph arising from, but not limited to, faulty manufacture, storage, handling, exposure, or processing

autoradiograph — the image of an object containing a radioelement obtained, on a recording medium, by means of its own radiation

back scattered radiation — radiation which is scattered more than 90 deg with respect to the incident beam, that is, backward in the general direction of the radiation source

betatron — an electron accelerator in which acceleration is provided by a special magnetic field constraining the electrons to a circular orbit. This type of equipment usually operates at energies between 10 and 31 MEV

blocking or masking — surrounding specimens or covering their sections with absorptive material

blooming — in radiologic real-time imaging, an undesirable condition exhibited by some image conversion devices and television pickup tubes brought about by exceeding the allowable input brightness for the device, causing the image to go into saturation, producing a fuzzy image of degraded spatial resolution and grey scale rendition

blow back — the enlargement of a minified radiograph to its original size by use of an optical direct reader

cassette — a light-tight container for holding radiographic recording media during exposure, for example, film, with or without intensifying or conversion screens

characteristic curve — the plot of density versus log of exposure or of relative exposure. (Also called the D-log E curve or the H and D curve.)

cine-radiography — the production of a series of radiographs that can be viewed rapidly in sequence, thus creating an illusion of continuity

collimator — a device of radiation absorbent material intended for defining the direction and angular divergence of the radiation beam

composite viewing — the viewing of two or more superimposed radiographs from a multiple film exposure

compton scatter radiation — the scattered X-ray or gamma ray, which results from the inelastic scattering of an incident X-ray or gamma ray on an electron. Since the ejected electron has short range in most materials, it is not considered part of the scattered radiation

computed radiology (photo stimulated luminescence method) — a two-step radiological imaging process; first, a storage phosphor imaging plate is exposed to penetrating radiation; second, the luminescence from the plate's photostimulable luminescent phosphor is detected, digitized, and presented via hard copy or a CRT

contrast sensitivity — a measure of the minimum percentage change in an object which produces a perceptible density/brightness change in the radiological image

contrast stretch — a function that operates on the greyscale values in an image to increase or decrease image contrast

definition, image definition — the sharpness of delineation of image details in a radiograph. Generally used qualitatively

densitometer — a device for measuring the optical density of radiograph film

density (film) — the quantitative measure of film blackening when light is transmitted or reflected.

$$D = \log (I_o/I) \text{ or } D = \log (I_o/R)$$

where

D = density

I_o = light intensity incident on the film

I = light intensity transmitted

R = light intensity reflected

density comparison strip — alternative term for *step-wedge comparison film.*

digital — the representation of data or physical quantities in the form of discrete codes, such as numerical characters, rather than a continuous stream

digital image — an image composed of discrete pixels, each of which is characterized by a digitally represented luminance level

digital image acquisition system — a system of electronic components which, by either directly detecting radiation or converting analog radiation detection information, creates an image of the spatial radiation intensity map comprised of an array of discrete digital intensity values (see *pixel*)

digital image enhancement — any operation used for the purpose of enhancing some aspect of the original image

digital image processing system — a system which uses algorithms to process digital image data

digitize (for radiology) — the act of converting an analog image or signal to a digital presentation

dynamic range (for radiology) — the span of signal intensity which defines the system's range of performance

equivalent I.Q.I. sensitivity — that thickness of I.Q.I. expressed as a percentage of the section thickness radiologically examined in which a 2T hole or 2% wire size equivalent would be visible under the same radiological conditions

equivalent penetrameter sensitivity — that thickness of penetrameter, expressed as a percentage of the section thickness radiographed, in which a 2T hole would be visible under the same radiographic conditions

erasable optical medium — an erasable and rewritable storage medium where the digital data is represented by the degree of reflectivity of the medium recording layer: the data can be altered

exposure, radiographic exposure — the subjection of a recording medium to radiation for the purpose of producing a latent image. Radiographic exposure is commonly expressed in terms of milliampere-seconds or millicurie-hours for a known source-to-film distance.

exposure table — a summary of values of radiographic exposures suitable for the different thicknesses of a specified material

film contrast — a qualitative expression of the slope or steepness of the characteristic curve of a film; that property of a photographic material which is related to the magnitude of the density difference resulting from a given exposure difference

film speed — a numerical value expressing the response of an image receptor to the energy of penetrating radiation under specified conditions

filter — uniform layer of material, usually of higher atomic number than the specimen, placed between the radiation source and the film for the purpose of preferentially absorbing the softer radiations

fluorescence — the emission of light by a substance as a result of the absorption of some other radiation of shorter wavelengths only as long as the stimulus producing it is maintained

fluorescent screen — alternative term for *intensifying screen (b)*

fluoroscopy — the visual observation on a fluorescent screen of the image of an object exposed to penetrating, ionizing radiation

focal spot — for x-ray generators, that area of the anode (target) of an x-ray tube which emits x-ray when bombarded with electrons

fog — a general term used to denote any increase in optical density of a processed photographic emulsion caused by anything other than direct action of the image forming radiation and due to one or more of the following:

(a) aging — deterioration, before or after exposure, or both, resulting from a recording medium that has been stored for too long a period of time, or other improper conditions;

(b) base — the minimum uniform density inherent in a processed emulsion without prior exposure

(c) chemical — resulting from unwanted reactions during chemical processing;

(d) dichroic — characterized by the production of colloidal silver within the developed sensitive layer;

(e) oxidation — caused by exposure to air during developing;

(f) exposure — arising from any unwanted exposure of an emulsion to ionizing radiation or light at any time between manufacture and final fixing;

(g) photographic — arising solely from the properties of an emulsion and the processing conditions, for example, the total effect of inherent fog and chemical fog;

(h) threshold — the minimum uniform density inherent in a processed emulsion without prior exposure.

fog density — a general term used to denote any increase in the optical density of a processed film caused by anything other than the direct action of the image-forming radiation

forward scattered radiation — radiation which is scattered less than 90 deg with respect to the incident beam, that is, forward in the general direction of the radiation source

gamma-radiography — a technique of producing radiographs using gamma-rays

gamma ray — electromagnetic penetrating radiation having its origin in the decay of a radioactive nucleus

geometric unsharpness — the penumbral shadow in a radiological image which is dependent upon:

(*a*) the radiation source dimensions;

(*b*) the source to object distance; and

(*c*) object to detector distance.

graininess — the visual impression of irregularity of silver deposit in a processed film

half-life — the time required for one half of a given number of radioactive atoms to undergo decay

half-value layer (HVL) — the thickness of an absorbing material required to reduce the intensity of a beam of incident radiation to one half of its original intensity

half-value thickness — the thickness of a specified substance which, when introduced into the path of a given beam of radiation, reduces its intensity to one half

image data file — a digital file containing radiological image and text information

image definition — see *definition*

image processing — a method whereby digital image data is transformed through a mathematical function

image quality indicator (IQI) — in industrial radiology, a device or combination of devices whose demonstrated image or images provide visual or quantitative data, or both, to determine radiologic quality and sensitivity. Also known as a penetrameter (disparaged).

NOTE 13 — It is not intended for use in judging size nor establishing acceptance limits of discontinuities.

indication — the response or evidence from a nondestructive examination that requires interpretation to determine relevance

intensifying screen — a material that converts a part of the radiographic energy into light or electrons and that, when in contact with a recording medium during exposure, improves the quality of the radiograph, or reduces the exposure time required to produce a radiograph, or both. Three kinds of screens in common use are:

(*a*) *metal screen* — a screen consisting of dense metal (usually lead) or of a dense metal compound (for example, lead oxide) that emits primary electrons when exposed to X- or gamma-rays;

(*b*) *fluorescent screen* — a screen consisting of a coating of phosphors which fluoresces when exposed to X or gamma radiation;

(*c*) *fluorescent-metallic screen* — a screen consisting of a metallic foil (usually lead) coated with a material that fluoresces when exposed to X or gamma radiation. The coated surface is placed next to the film to provide fluorescence; the metal functions as a normal metal screen.

IQI sensitivity — in radiography, the minimum discernible image and the designated hole in the plaque-type, or the designated wire image in the wire type image quality indicator

keV (kilo electron volt) — a unit of energy equal to one thousand electron volts, used to express the energy of X rays, gamma rays, electrons, and neutrons

kV (kilo volt) — a unit of electrical potential difference equal to one thousand volts, used to describe the accelerating potential of an X-ray tube

latent image — a condition produced and persisting in the image receptor by exposure to radiation and able to be converted into a visible image by processing

lead screen — see *intensifying screen (a)*

line pair test pattern — a pattern of one or more pairs of objects with high contrast lines of equal width and equal spacing. The pattern is used with an imaging device to measure spatial resolution.

linear accelerator — an electron generator in which the acceleration of the particles is connected with the propagation of a high-frequency field inside a linear or corrugated waveguide

line pairs per millimetre — a measure of the spatial resolution of an image conversion device. A line pair test pattern consisting of one or more pairs of equal width, high contrast lines, and spaces is utilized to determine the maximum density of lines and spaces that can be successfully imaged. The value is expressed in line pairs per millimetre.

location marker — a number or letter made of lead (Pb) or other highly radiation attenuative material that is placed on an object to provide traceability between a specific area on the image and the part

low-energy gamma radiation — gamma radiation having energy less than 200 keV

luminosity — a measure of emitted light intensity

mA (milli ampere) — a unit of current equal to 0.001 amperes, used to express the tube current of an X-ray tube

magnetic storage medium — a storage medium that uses magnetic properties (magnetic dipoles) to store digital data (for example, a moving drum, disk, or tape or a static core or film)

MeV (mega or million electron volts) — a unit of energy equal to one million electron volts, used to express the energy of X rays, gamma rays, electrons, and neutrons

micro focus X-ray tube — an X-ray tube having an effective focal spot size not greater than 100 μm

milliamperes (mA) — the technical term is *tube current* and is defined as the current passing between the cathode and anode during the operation of an x-ray tube, measured in milliamperes (mA) and usually taken as a measure of x-ray intensity

minifocus X-ray tube — an X-ray tube having an effective focal spot size between 100 and 400 μm

MV (mega or million volt) — a unit of electrical potential difference equal to one million volts, used to describe the accelerating potential of an X-ray tube

net density — total density less fog and support (film base) density

neutron radiography (NRT) — a process of making an image of the internal details of an object by the selective attenuation of a neutron beam by the object

noise — the data present in a radiological measurement which is not directly correlated with the degree of radiation attentuation by the object being examined

nonerasable optical data — a nonerasable, nonrewriteable storage medium where the digital data is represented by the degree of reflectivity of the medium's recording layer. The data cannot be altered.

nonscreen-type film (direct-type film) — X-ray film designed for use with or without metal screens, but not intended for use with salt screens

nuclear activity — the number of disintegrations occurring in a given quantity of material per unit of time. *Curie* is the unit of measurement. One curie is equivalent to 3.7×10^{10} disintegrations per second.

object-film distance — the distance between the surface of the source side object and the plane of the recording medium

NOTE 14 — In the case where the recording medium is placed directly in contact with the object being examined, the distance is equal to the thickness of the object.

optical density — the degree of opacity of a translucent medium (darkening of film) expressed as follows:

$$OD = \log (I_o/I)$$

where:

OD = optical density

I_o = light intensity incident on the film

I = light intensity transmitted through the film

optical line pair test pattern — see *line pair test pattern*

pair production — the process whereby a gamma photon with energy greater than 1.02 MeV is converted directly into matter in the form of an electron-positron pair. Subsequent annihilation of the positron results in the production of two 0.511 MeV gamma photons.

pencil beam — a radiation beam which has little divergence, usually created by collimating an intense source of radiation

penetrameter — alternative term for *image quality indicator.*

penetrameter sensitivity — alternative term for *IQI sensitivity.*

phosphor — any substance that can be stimulated to emit light by incident radiation

photo fluorography — a photograph of the image formed on a fluorescent screen

photostimulable luminescence — the physical phenomenon of phosphors absorbing incident ionizing radiation, storing the energy in quasi-stable states and emitting luminescent radiation proportional to the absorbed energy when stimulated by radiation of a different wavelength

photostimulable luminescent phosphor —a phosphor capable of storing a latent radiological image, which, upon laser stimulation, will generate luminescence proportional to the radiation intensity

pixel — the smallest addressable element in an electronic image

pixel, display size — the dimensions of the smallest picture element comprising the displayed image, given in terms of the imaged object's dimensions being represented by the element

pixel size — the length and width of a pixel

primary radiation — radiation coming directly from the source

radiograph — a permanent, visible image on a recording medium produced by penetrating radiation passing through the material being tested

radiographic contrast — the difference in density between an image and its immediate surroundings on a radiograph

radiographic equivalence factor — that factor by which the thickness of a material must be multiplied in order to determine what thickness of a standard material (often steel) will have the same absorption

radiographic exposure — see *exposure*

radiographic inspection — the use of X-rays or nuclear radiation, or both, to detect discontinuities in material, and to present their images on a recording medium.

radiographic quality — a qualitative term used to describe the capability of a radiograph to show flaws in the area under examination

radiographic sensitivity — a general or qualitative term referring to the size of the smallest detail that can be seen on a radiograph, or the ease with which details can be seen

radiography — the art, act, or process of making radiographs

radiological examination — the use of penetrating ionizing radiation to display images for the detection of discontinuities or to help ensure integrity of the part

radiology — the science and application of X-rays, gamma-rays, neutrons, and other penetrating radiations

radioscopy — the electronic production of a radiological image that follows very closely the changes with time of the object being imaged

rare earth screens — see *intensifying screen*

real-time radioscopy — radioscopy that is capable of following the motion of the object without limitation of time

recording media — material capable of capturing or storing, or both, a radiological image in digital or analog form

recording medium — a film or detector that converts radiation into a visible image

representative quality indicator (RQI) — an actual part or similar part of comparable geometry and attentuation characteristics to that of the test part(s), that has known or measurable features, or both, representing the facets of nonconformance for which the test part is to be examined

scintillators and scintillating crystals — a detector that converts ionizing radiation to light

screen — alternative term for intensifying screen

secondary radiation — radiation emitted by any substance as the result of irradiation by the primary source

sensitivity — see *contrast sensitivity, equivalent IQI sensitivity, equivalent penetrameter sensitivity, IQI sensitivity, radiographic sensitivity*

shim — a material, typically placed under the IQI, which is radiologically similar to the object being imaged

signal — the data present in a radiological measurement which is directly correlated with the degree of radiation attenuation by the object being examined

source — a machine or radioactive material that emits penetrating radiation

source-film distance — the distance between the radiation producing area of the source and the film

step wedge — a device with discrete step thickness increments used to obtain an image with discrete density step values

step-wedge calibration film — a step-wedge comparison film the densities of which are traceable to a nationally recognized standardizing body

step-wedge comparison film — a strip of processed film carrying a stepwise array of increasing photographic density

step wedge comparison film — a radiograph with discrete density steps that have been verified by comparison with a calibrated step wedge film

storage phosphor imaging plate — a flexible or rigid reusable detector that stores a radiological image as a result of exposure to penetrating radiation

subject contrast — the ratio (or the logarithm of the ratio) of the radiation intensities transmitted by selected portions of the specimen

system induced artifacts — anomalies that are created by a system during the acquisition, display processing, or storage of a digital image

system noise — the noise present in a radiological measurement resulting from the individual elements of the radiological system

target — that part of the anode of an X-ray emitting tube hit by the electron beam

tenth-value-layer (TVL) — the thickness of the layer of a specified substance which, when introduced into the path of a given narrow beam of radiation reduces the intensity of this radiation by a factor of ten

tomography — any radiologic technique that provides an image of a selected plane in an object to the relative exclusion of structures that lie outside the plane of interest (see *tomogram* and *(CT) computed tomography)*

total image unsharpness — the blurring of test object features in a radiological image resulting from any cause(s)

translucent base media — materials with properties that allow radiological interpretation by transmitted or reflected light

transmission densitometer — an instrument that measures the intensity of the transmitted light through a radiographic film and provides a readout of the transmitted film density

transmitted film density — the density of radiographic film determined by measuring the transmitted light

tube current — the current, measured in milliamperes, passing between the cathode and anode during the operation of an X-ray tube

tube current — the transfer of electricity, created by the flow of electrons, from the filament to the anode target in an X-ray tube; usually expressed in unit of milliamperes

vacuum cassette — a flexible light-tight container that, when operated under a vacuum, holds film and screen in intimate contact during a radiographic exposure

TABLE 1
COMPOSITION AND PARTIAL PRESSURES OF THE ATMOSPHERE

Constituent	Volume %	Partial Pressure, kPa
At sea level (atmospheric pressure is 101 kPa)		
Oxygen	21	(0.21 × 101 =) 21
Nitrogen	78	(0.78 × 101 =) 79
Others	1	(0.01 × 101 =) 1
		Total atmospheric pressure, 101
At 3700-m altitude (atmosphere pressure is 64 kPa)		
Oxygen	21	(0.21 × 64 =) 13
Nitrogen	78	(0.78 × 64 =) 50
Others	1	(0.01 × 64 =) 1
		Total atmospheric pressure, 64

8. Leak Testing

absolute manometer — a manometer whose calibration can be calculated from the measurable physical constants of the instrument and for which calibration is the same for all ideal gases

absolute pressure — pressure above the absolute zero corresponding to empty space, that is, local atmospheric pressure plus gage pressure

absorption — in leak testing, the binding or incorporation of gas in the interior of a solid (or liquid)

accumulation test — a leak test used to detect very small leaks in which gas contained in a component being tested will, if a leak is present, collect for a specified period of time in a closed evacuated chamber into which the component has been placed. At the end of the test period the chamber is opened to a leak detector which is sensitive to the gas.

alkali ion diode — a sensor for halogen gases. See also *halogen leak detector (2).*

aperture leak — a leak of such geometric configuration that the length of the leakage path is much smaller than the shortest diameter of the path, so that the leak may be considered the equivalent of an opening in an infinitesimally thin wall

atmosphere (standard) — the pressure exerted by a mercury column 760 mm in height at 0°C under standard acceleration of gravity; equivalent to 101 325 Pa

atmospheric pressure — the pressure of the atmosphere at a specified place and time (see Table 1)

atomic mass unit (amu) — the unit of measure of the mass of a particle (atom, molecule, ion, etc.), defined as $^1/_{12}$ of the mass of carbon-12. The numerical value of the mass of a particle in terms of amu is identical with the older atomic weight.

audible leak indicator — an accessory to a leak detector which converts the output signal to an audible note whose frequency is a function of the leakage rate

back pressure — same as *forepressure*

back pressure test — same as *pressure-evacuation test*

background signal — in leak testing, the steady or fluctuating output signal of the leak detector caused by the presence of residual tracer gas or other substance to which the detecting element responds

backing pump — same as *fore pump*

backing space — the space between a backing pump (fore pump) and the associated diffusion pump (or other type of pump requiring a fore pump). See also *ballast.*

backing space technique — a method of testing for leaks in which the leak detector is connected to the backing space to take advantage of the compression of gas that occurs between the vacuum system and the backing pump, due to the action of the diffusion pump (or other type of pump of high speed relative to its backing pump)

bake-out — in leak testing, the degassing of a vacuum system by heating during the pumping process

ballast — in leak testing, a backing space large enough to maintain a low forepressure when the fore pump is temporarily stopped

Bayard-Alpert ionization gage — see *ionization vacuum gage*

bell jar — a container, open at one end (usually the bottom), which is used as a vacuum chamber or test vessel

bell jar testing — a test used for detecting leakage from an object completely or partially filled with a tracer gas and placed in a vacuum chamber or bell jar

bomb test — see *pressure-evacuation test*

bubble immersion test — a form of leak test of gas-containing enclosures in which a leak is indicated by the formation of a bubble at the site of a leak

clean-up — in leak testing, the time required for a leak testing system to reduce its signal output to 37% of the signal indicated at the time the tracer gas ceases to enter the leak system. Also called clean-up time.

clusec — an obsolete unit of flow rate equal to 10-2 lusecs

cold-cathode ionization gage — see *ionization vacuum gage*

concentration ratio — in leak testing, the ratio of the number of atoms (molecules) of a given constituent of a (gas) mixture to the total number of atoms (molecules) in the mixture. For ideal gases the concentration ratio has the same value as the volume fraction or the partial pressure of the constituent.

conductance — in leak testing, the ratio of the throughput (under steady state, conservative conditions) of a gas flowing through a conduit or an orifice to the difference in the partial pressures of the gas at the two ends of the conduit or on the two sides of the orifice, expressed in volume units per unit time, such as cubic metres per second

cracking — in leak testing, same as *dissociation*

differential leak detector — a leak detector employing two similar gage tubes in a bridge circuit with a trap which is selective for the tracer gas between the system and one of the tubes

differential Pirani gage — a leak detecting device employing two similar Pirani tubes as arms of a Wheatstone bridge

diffusion — in leak testing, the flow of the gas through a substance in which the gas actually migrates through the crystal lattice of the substance rather than through a geometrical leak (molecular diameters versus hole dimension)

discharge pressure — in leak testing, same as *forepressure*

discharge tube leak indicator — a glass tube attached to a system being leak tested, with the glass tube having electrodes attached to a source of high-frequency high voltage, such as a Tesla coil or induction coil, so that changes in the color of the electrical discharge can be observed when a suitable tracer gas (methane, carbon dioxide, alcohol) flows through the leak

dissociation — in leak testing, the breakdown of a substance into two or more constituents

NOTE 15 — Dissociation is sometimes referred to as cracking.

drift — in leak testing, the relatively slow change in the background output level of the leak detector due to the electronics rather than a change in the level of the tracer gas

dynamic leak test — a form of leak test in which some of the tracer gas entering through a leak is continually removed for sensing purposes

dynamic leakage measurement — leakage determined by measuring the tracer gas equilibrium partial pressure while the system is actively being pumped

dynamic sensitivity of leak detector — the minimum leak rate that the detector is capable of detecting while the enclosure under test is actively being evacuated continuously under specified conditions

equivalent nitrogen pressure — the calculated pressure that a gage or another device would indicate if the gas in the device were replaced by nitrogen at the same molecular density

exhaust pressure — in leak testing, same as *forepressure*

exhaust tubulation — same as *pump-out tubulation*

flooded system — a system which, while being tested, becomes so filled with tracer gas as to make impracticable further leak testing

flow — same as *flow rate*

flow rate — in leak testing, *(1)* the rate at which gas passes a given cross section of a system, determined by the product of the volume passing per unit time and its (partial) pressure at the cross section; *(2)* a product of the (partial) pressure difference of a gas at the ends of a conduit or across the face of an orifice, and the conductance of the gas for the conduit or orifice. Expressed in pressure-volume per unit time, such as pascal cubic metres per second.

fore-line — in leak testing, the line between a fore pump and the pump it backs

fore-line valve — in leak testing, a vacuum valve placed in the fore-line to permit isolation of the diffusion pump from its backing pump

forepressure — in leak testing, the total pressure on the outlet side of a pump measured near the outlet port. Sometimes called the back pressure, backing pres-

sure, outlet pressure, exhaust pressure, or discharge pressure. In discussing the action of a vapor jet, the term forepressure may be used to designate the total pressure of the gas against which the jet impinges.

fore pump — in leak testing, the pump that produces the necessary fore vacuum for a pump which is incapable of discharging gases at atmospheric pressure. Sometimes called the backing pump.

gage pressure — difference between the absolute pressure and atmospheric pressure

gas — the state of matter in which the molecules are practically unrestricted by intermolecular forces so that the molecules are free to occupy all space within an enclosure. In vacuum technology, the word gas has been loosely applied to the uncondensed gas and vapor within a vacuum system.

halogen — any element of the family of the elements fluorine, chlorine, bromine, and iodine. Compounds do not fall under the strict definition of halogen. However, for the purpose of this standard, this word provides a convenient descriptive term for halogen-containing compounds. Of significance in halogen leak detection are those which have enough vapor pressure to be useful as tracer gases.

halogen leak detector — a leak detector that responds to halogen tracer gases. Also called halogen-sensitive leak detector or halide leak detector. *(1)* The copper-flame detector or halide torch consists of a bunsen burner with flame impinging on a copper plate or screen, and a hose with sampling probe to carry tracer gas to the air intake of the burner. *(2)* The alkali-ion diode halogen detector depends on the variation of positive ion emission from a heated platinum anode when halogen molecules enter the sensing element.

helium bombing — a pressure-evacuation test in which helium is used as the test gas

helium drift — *(1)* in leak testing with a probe, the drift from a leak or permeable gasket located at some distance from the end of the probe but which is detected by the probe and can mislead the operator into suspecting the area near the probe; *(2)* a gradual wandering of the output meter needle of the leak detector due to slowly changing helium concentrations (either due to a leak or outgassing) in the detector tube. Expressed in scale divisions per unit time.

helium leak detector — a leak detector using helium as the tracer gas

hermetically tight seal — a seal which does not exhibit leakage when dynamically tested with commercially built leak detectors that are sensitive to a gas on the pressure side opposite to the side on which the leak detector is located, or which does not exhibit leakage with any form of liquid test

TABLE 2
DEGREES OF VACUUM

Degrees of Vacuum	Approximate Pressure Range
Low	100 kPa to 3 kPa
Medium	3 kPa to 0.1 Pa
High	0.1 Pa to 0.1 mPa
Very high	0.1 mPa to 0.1 μPa
Ultra high	0.1 μPa and less

high vacuum — see Table 2

holding pump — a fore pump used to hold a vapor pump at operating conditions while a roughing pump reduces the system pressure to a point at which the valve between the vapor pump and the system can be opened without stopping the flow of vapor from the nozzles

hood test — an overall test in which an object under vacuum test is enclosed by a hood which is filled with tracer gas so as to subject all parts of the test object to examination at one time. A form of dynamic leak test in which the entire enclosure or a large portion of its external surface is exposed to the tracer gas while the interior is connected to a leak detector with the objective of determining the existence of leakage.

hot-cathode ionization gage — see *ionization vacuum gage*

hot-filament ionization gage — see *ionization vacuum gage*

hydraulic pressure test — same as *hydrostatic test*

hydrostatic test — in leak testing, a pressure test in which the component being tested is filled completely with water or another liquid. Pressure, if required, is then applied to the liquid for the required time and the outside of the component is examined visually for leaks.

ideal gas — a gas that obeys Boyle's law and has zero heat of free expansion (or also obeys Charles' law). Also known as a perfect gas.

in-leakage rate — the combined leakage rate from all existing leaks in a specified evacuated vessel in pressure volume units per unit of time

inlet — the opening, flange, connection, or coupling on a leak detector or leak testing system through which the tracer gas may enter due to a leak in an object under test

inlet flange — see *inlet*

inlet port — see *inlet*

inside-out testing — see *bell jar testing*

ion pump — an electrical device for pumping gas comprising a means for ionizing the gas and a system of electrodes at suitable potentials, and in some cases also a magnetic field, which causes the ions formed to move towards a surface on which they are absorbed or buried

ion source — in leak testing, that part of a leak detector tube in which tracer gas is ionized preliminary to being detected

ionization potential — the minimum energy, expressed in (electron) volts, required to remove an electron from an atom or molecule to form a positive ion

ionization vacuum gage — a vacuum gage comprising a means of ionizing the gas molecules, electrodes to facilitate the collection of the positive ions formed, and means of indicating the magnitude of the collected ion current. Various types of ionization gages are distinguished according to the method of producing the ionization. The common types are as follows:

(a) hot-cathode ionization gage — the ions are produced by collisions with electrons emitted from a hot filament (or cathode) and accelerated by an electric field. Also called hot-filament ionization gage, or simply ion gage. The Bayard-Alpert ionization gage employs a tube with an electrode structure designed to minimize X-ray-induced electron emission from the ion collector.

(b) cold-cathode ionization gage — the ions are produced by a cold-cathode discharge, usually in the presence of a magnetic field which lengthens the path of the electrons between cathode and anode. The discharge tube is a transparent tube in which the color and form of a cold-cathode discharge (without the presence of a magnetic field) gives an indication of the pressure and the nature of the gas. The Phillips ionization gage is a cold-cathode ionization gage in which a magnetic field is directly parallel to the axis of an annular electrode (normally the anode) located between two plate electrodes perpendicular to the axis. Various modifications of the Penning gage are named after the inventors, and certain types are referred to as magnetron vacuum gages.

(c) radioactive ionization gage — the ions are produced by radiations (usually alpha particles) emitted from a radioactive source

isolation test — in leak testing, a method of determining whether a leak is present in a system, or of obtaining an estimate of its magnitude, by observing the rate of rise of pressure in the evacuated system when the system is isolated from the pump. See also *rate of rise.*

TABLE 3
CONVERSION FACTORS FOR LEAK TESTING

To Convert from	To	Multiply Column 1 by
Leakage Rate:		
atm·cm^3/s	Pa·m^3/s	1.10×10^{-1}
micron·litres/s	Pa·m^3/s	1.33×10^{-4}
micron·ft^3/h	Pa·m^3/s	1.05×10^{-4}
pascal·litres/s	Pa·m^3/s	1.00×10^{-3}
STD·cm^3/s	Pa·m^3/s	1.01×10^{-1}
torr·litres/s	Pa·m^3/s	1.33×10^{-1}
Pressure:		
atmosphere (std)	Pa	1.01×10^{5}
bar	Pa	1.00×10^{5}
micrometre of Hg	Pa	1.33×10^{-1}
micron	Pa	1.33×10^{-1}
millimetre of Hg	Pa	1.33×10^{2}
pounds·force/in.^{2}	Pa	6.89×10^{3}
torr	Pa	1.33×10^{2}
Viscosity:		
centipoise	Pa·s	1.00×10^{-3}
poise	Pa·s	1.00×10^{-1}
Volume:		
cm^3	m^3	1.00×10^{-4}
ft^3	m^3	2.83×10^{-2}
litre	m^3	1.00×10^{-3}

Krypton 85 — a tracer gas used to test for leakage when the radioisotope leak test method is used

leak — a hole, or void in the wall of an enclosure, capable of passing liquid or gas from one side of the wall to the other under action of pressure or concentration differential existing across the wall, independent of the quantity of fluid flowing

leak artifact — a device used to introduce gas into a system at a controlled rate, usually 10^{-7} mol/s or less

leak detector — a device for detecting, locating, or measuring, or combination thereof, leakage

leakage rate — the flow rate of a liquid or gas through a leak at a given temperature as a result of a specified pressure difference across the leak. Standard conditions for gases are 25°C and 100 kPa. Leakage rates are expressed in various units such as pascal cubic metres per second or pascal litres per second (see Table 3).

leak testing — comprises procedures for detecting or locating or measuring leakage, or combinations thereof

low vacuum — see Table 2

lusec — a unit of flow rate equal to 0.133 mPa · m^3/s

masking — in leak testing, the covering of a section of a test object so as to prevent tracer gas from entering leaks that may exist in the covered section

mass number — the whole number nearest to the atomic mass expressed in either atomic mass units or as (chemical) atomic weight

mass spectrometer (M.S.) — an instrument that is capable of separating ionized molecules of different mass to charge ratio and measuring the respective ion currents. The mass spectrometer may be used as a vacuum gage that relates an output which is proportioned to the partial pressure of a specified gas, as a leak detector sensitive to a particular tracer gas, or as an analytical instrument to determine the percentage composition of a gas mixture. Various types are distinguished by the method of separating the ions. The principal types are as follows:

(a) *Dempster (M.S.)* — The ions are first accelerated by an electric field through a slit, and are then deflected by a magnetic field through 180 deg. so as to pass through a second slit.

(b) *Bainbridge-Jordan (M.S.)* — The ions are separated by means of a radial electrostatic field and a magnetic field deflecting the ions through 60 deg. so arranged that the dispersion of ions in the electric field is exactly compensated by the dispersion in the magnetic field for a given velocity difference.

(c) *Bleakney (M.S.)* — The ions are separated by crossed electric and magnetic fields. Also called cross fields (M.S.).

(d) *Nier (M.S.)* — A modification of the Dempster (M.S.) in which the magnetic field deflects the ions.

(e) *Time of Flight (M.S.)* — The gas is ionized by a pulse-modulated electron beam and each group of ions is accelerated toward the ion collector. Ions of different mass to charge ratios traverse their paths in different times.

(f) *Radio-Frequency (M.S.)* — The ions are accelerated into a radio-frequency analyzer in which ions of a selected mass to charge are accelerated through openings in a series of spaced plates alternately attached across a radio-frequency oscillator. The ions emerge into an electrostatic field which permits only the ions accelerated in the analyzer to reach the collector.

(g) *Omegatron (M.S.)* — The ions are accelerated by the cyclotron principle.

mass spectrometer leak detector — a mass spectrometer adjusted to respond only to the tracer gas

mass spectrum — a record, graph, table, etc., that shows the relative number of ions of various mass that are produced when a given substance is processed in a mass spectrometer

mean free path — the average distance that a molecule travels between successive collisions with other molecules

medium vacuum — see Table 2

micrometre — a unit of length equal to one millionth of a metre

micron — a term for micrometre

micron of mercury — a unit of pressure equal to that exerted by a column of mercury standing one micrometre high

millimetre of mercury — a unit of pressure corresponding to a column of mercury exactly 1 mm high under standard acceleration of gravity. Sometimes called torr.

minimum detectable leakage rate — the magnitude of the smallest leakage rate that can be unambiguously detected by a given leak detector in the presence of conditions existing at time of test

molecular flow — the flow of gas through a passage under conditions such that the mean-free path is greater than the largest dimension of a transverse section of the passage

molecular leak — a leak of such geometric configuration that gas flow through it obeys the laws of molecular flow (Knudsen's law). The flow is proportional to the difference of the end pressures and inversely proportional to the square root of the molecular weight of the gas.

newton (N) — the SI unit of force ($kg \cdot m/s^2$)

noncondensable gas — a gas whose temperature is above its critical temperature, so that it cannot be liquefied by increase of pressure alone

occlusion — the trapping of undissolved gas in a solid during solidification

outgassing — the evolution of gas from a material in a vacuum.

outlet pressure — see *forepressure*

palladium barrier leak detector — a leak detector using hydrogen as the tracer gas and using the principle of hydrogen diffusing through a hot palladium barrier into an evacuated vacuum gage

partial pressure — the pressure caused by a gas, either by itself, or in the presence of other gases. When a second gas is not present, the partial pressure is the same as the total pressure.

pascal (Pa) — one pascal is approximately equal to 1×10^{-5} atm or, more precisely, 1 Pa = 0.98692×10^{-5} atm

pascal cubic metres per second ($Pa \cdot m^3/s$) — the preferred unit of gas flow in the SI system. One $Pa \cdot m^3/s$ is approximately equal to 10 atm cm^3/s or, more precisely, 1 $Pa \cdot m^3/s$ = 9.8692 $atm \cdot cm^3/s$.

Penning gage — see *ionization vacuum gage*

perfect gas — see *ideal gas*

permeability coefficient — the steady-state rate of flow of gas through unit area and thickness of a solid barrier per unit pressure differential at a given temperature

Phillips ionization gage — see *ionization vacuum gage*

Pirani gage — see thermal conductivity vacuum gage

Poiseuille flow — the particular case of laminar viscous flow through a long pipe of circular cross section

pressure difference — in leak testing, the difference between the pressure on the inlet side of the leak and the pressure on the exit side of the leak

pressure dye test — *(1)* a form of leak test in which the item or items to be tested are filled with a liquid dye or fluorescent oil which is then pressurized for the purpose of driving the liquid through possible leakage paths with the presence of the leaks being visible when viewed from the exterior; *(2)* a form of leak test in which the item or items to be tested are immersed in a liquid dye or fluorescent oil which is then pressurized for the purpose of driving liquid into possible leakage paths with their presence being visible when the excess liquid has been removed from the exterior.

pressure-evacuation test — a leak test in which one or more devices are placed under gas pressure for a period of time, the objective being to accumulate enough gas in those devices that may leak to permit an indication on a leak detector sensitive to the gas when the devices are placed in an evacuated system joined to the leak detector

pressure probe — see *probe*

pressure testing — a method of leak testing in which the component being tested is filled completely with a gas or liquid which is then pressurized. The outside of the component is examined for the detection of any leaks.

probe — in leak testing, a tube having an opening at one end, used for directing or collecting a stream of tracer gas

probe gas — in leak testing, a tracer gas which issues from an orifice so as to impinge on a restricted test area

probe test — a leak test in which the tracer gas is applied by means of a probe so that the area covered by the tracer gas is localized. This enables the individual leaks to be located.

proportioning probe — in leak testing, a probe that can vary sample to pure air ratios between 100% sample and 100% pure air without substantially changing the total flow from the probe

pump-down time — time of evacuation

pump-out tubulation — a tube extending from an evacuated device through which gas is pumped and which is usually permanently sealed off after the device has been evacuated. Sometimes called exhaust tubulation.

radioisotope leak test system — a leak test system which uses a radioactive tracer gas and a detector for measuring the emission from the tracer

rate of rise — in leak testing, the time rate of pressure increase at a given time in a vacuum system which is suddenly isolated from the pump by a valve. The volume and temperature of the system are held constant during the rate of rise measurement. See *isolation test.*

resistance (to flow) — the reciprocal of conductance

response factor — in leak testing, the response of the halogen leak detector 0.3 $MPa \cdot m^3/s$ of refrigerant-12 (dichloro-difluoromethane, CC12F2) or less, divided by the response to the same quantity of another halogen test gas. Thus, the actual leak rate of a detected leak will be the indication of the detector multiplied by the response factor. The response of mixture of a tracer and nonhalogen gases will be the response factor of the tracer divided by the fraction of tracer gas in the test gas.

response time — the time required for a leak detector or leak testing system to yield a signal output equal to 63% of the maximum signal attained when tracer gas is applied continuously to the system under test. Also called response.

roughing — in leak testing, the initial evacuation of a vacuum system

roughing line — in leak testing, a line running from a mechanical pump to a vacuum chamber through which preliminary pumping is conducted in the rough vacuum range

roughing pump — in leak testing, a vacuum pump used for the initial evacuation of a vacuum system

sampling probe — in leak testing, a device used to collect tracer gas from an area of the test object and feed it to the leak detector at the reduced pressure required. Also called a sniffing probe.

scattering — in leak testing, dispersion or diffusion in various directions due to intermolecular or ionic collisions as applied to the effect of the residual gas in a mass spectrometer tube or an ion beam traversing the tube

search-gas — same as *tracer gas*

sensitivity — in the case of a leak detector, the response of the detector to tracer gas leakage (that is, scale divisions per unit of leakage rate)

sensitivity of leak test — the smallest leakage rate that an instrument, method, or system is capable of detecting under specified conditions. See *minimum detectable leakage rate.*

sniffing probe — same as *sampling probe*

sorption — the taking up of gas by absorption, adsorption, chemisorption, or any combination of these processes

spark coil leak detector — a high-frequency discharge coil of the Tesla type which indicates pin holes in glass vacuum systems by a spark jumping between the core of the coil and the pin hole

spectrometer tube — the sensing element of a mass spectrometer leak detector

spray probe — in leak testing, a device for directing a small jet of tracer gas on an object under vacuum testing

squealer — same as *audible leak indicator*

standard leak — a device that permits a tracer gas to be introduced into a leak detector or leak testing system at a known rate to facilitate calibration of the leak detector

standard leakage rate — the rate of flow of atmospheric air under conditions in which: inlet pressure is 0.1 MPa ± 5%; outlet pressure is less than 1 kPa; temperature is 25°C ± 5°C; and dew point is less than −25°C.

thermal conductivity vacuum gage — a vacuum gage containing two surfaces at different temperatures between which heat can be transported by the gas molecules so that changes in the temperature (or in the heating power required to maintain constant temperature) of one of the surfaces can be correlated with the gas pressure. Various types of thermal conductivity gages are distinguished according to the method of indicating the temperature change. The common types are listed below:

(a) Pirani Gage. An increase of pressure from the zero point causes a decrease in the temperature of a heated filament of material having a large temperature coefficient of resistance thus unbalancing a Wheatstone bridge circuit (or the circuit is adjusted to maintain the filament temperature constant).

(b) Thermocouple Gage. The decrease in temperature of a heated filament as the pressure rises is indicated by decreased emf in a thermocouple circuit having the junction in thermal contact with the center of the heated filament.

(c) Thermistor Gage. A form of Pirani gage employing a thermistor as the heated element.

(d) Bimetallic Strip Gage. Deflection of a bimetallic strip with changing temperature indicates the changes in pressure.

thermocouple gage — see *thermal conductivity vacuum gage*

throttling — in leak testing, reducing the net pumping speed of a pumping system by partially closing a valve or installing a section of pipeline with low conductance

throughput — same as *flow rate (1).*

tight — in leak testing, free from leaks according to a given specification

torr — a unit of pressure equal to 1/760th of an atmosphere

tracer gas — a gas which, passing through a leak, can then be detected by a specific leak detector and thus disclose the presence of a leak. Also called search gas.

tracer probe leak location — same as *probe test.*

transition flow — in leak testing, the flow of gases under conditions intermediate between laminar viscous flow and molecular flow

ultra-high vacuum — see Table 2

ultrasonic leak detector — an instrument that detects ultrasonic energy produced by molecular turbulence that occurs in the transition from laminar to turbulent flow of a gas through an orifice and that converts this energy to a usable signal

vacuum — in vacuum technology, a given space filled with gas at pressures below atmospheric pressure (see Table 2)

vacuum testing — *(1)* a method of testing for leaks in which the object under test is evacuated and the tracer gas applied to the outside surface of the object; *(2)* a leak-testing procedure in which the enclosure under examination is evacuated, the tracer gas applied to the outside surface of the enclosure, and the gas detected after entering the enclosure.

vapor pressure — the pressure exerted by the vapor of a solid or liquid when in equilibrium with the solid or liquid

very high vacuum — see Table 2

virtual leak — *(1)* the semblance of a leak in a vacuum system caused by slow release of trapped gas. *(2)* during a rate-of-rise test, the semblance of a leak in a vacuum system caused by slow release of sorbed or occluded gas or gases on or in the surfaces and pores of all materials in a system which has been exposed to atmospheric pressure prior to evacuation.

viscous flow — the flow of gas through a duct under conditions such that the mean free path is very small in comparison with the smallest dimension of a transverse

section of the duct. This flow may be either laminar or turbulent.

viscous leak — a leak of such geometric configuration that gas flow through it is viscous in nature; that is, the flow obeys Poiseuille's Law. The flow rate is proportional to the difference of the squares of the end pressures, and inversely proportional to the gaseous viscosity.

9. Liquid Penetrant Examination

angstrom unit (Å) — a unit of length which may be used to express the wavelength of electromagnetic radiation, that is, light. One angstrom unit is equal to 0.1 nanometres. (1 nm = 10^{-9} m.)

background — the surface of the test part against which the indication is viewed. It may be the natural surface of the test part or the developer coating on the surface.

black light — electromagnetic radiation in the near-ultraviolet range of wavelength. (330–390 nm) (3300–3900 Å)

black light filter — a filter that transmits near-ultraviolet radiation while absorbing other wavelengths

bleedout — the action of an entrapped liquid penetrant in surfacing from discontinuities to form indications

blotting — the action of the developer in soaking up the penetrant from the discontinuity to accelerate bleedout

carrier — a liquid, either aqueous or nonaqueous, in which liquid penetrant examination materials are dissolved or suspended

clean — free of contaminants

contaminant — any foreign substance present on the test surface or in the inspection materials which will adversely affect the performance of liquid penetrant materials

contrast — the difference in visibility (brightness or coloration) between an indication and the background

detergent remover — a penetrant remover that is a solution of a detergent in water

developer — a material that is applied to the test surface to accelerate bleedout and to enhance the contrast of indications

developer, aqueous — a suspension of developer particles in water

developer, dry powder — a fine free-flowing powder used as supplied

developer, liquid film — a suspension of developer particles in a vehicle which leaves a resin/polymer film on the test surface after drying

developer, nonaqueous — developer particles suspended in a nonaqueous vehicle prior to application

developer, soluble — a developer completely soluble in its carrier, not a suspension of powder in a liquid, which dries to an absorptive coating

developing time — the elapsed time between the application of the developer and the examination of the part

dragout — the carryout or loss of penetrant materials as a result of their adherence to the test pieces

drain time — that portion of the dwell time during which the excess penetrant or emulsifier drains from the part

drying oven — an oven used for increasing the evaporation rate of rinse water or an aqueous developer vehicle from test parts

drying time — the time required for a cleaned, rinsed, or wet developed test part to dry

dwell time — the total time that the penetrant or emulsifier is in contact with the test surface, including the time required for application and the drain time

electrostatic spraying — a technique for attaining a uniform coating in which the material sprayed is given an electrical charge

eluant — a liquid used to extract one material from another, as in chromatography

emulsification time — the time that an emulsifier is permitted to remain on the part to combine with the surface penetrant prior to removal. Also called emulsification dwell time.

emulsifier — a liquid that interacts with an oily substance to make it water-washable

emulsifier, hydrophilic — a water-based liquid used in penetrant examination which interacts with the penetrant oil, rendering it water-washable

emulsifier, lipophilic — an oil based liquid used in penetrant examination which interacts with the penetrant oil, rendering it water-washable

etching — the removal of surface material by chemical or electrochemical methods

family — a complete series of penetrant materials required for the performance of a liquid penetrant examination

fluorescence — the emission of visible radiation by a substance as a result of, and only during, the absorption of black light radiation

footcandle (fc) — the illumination on a surface, 1 ft^2 in area, on which is uniformly distributed a flux of 1 lm (lumen). It equals 10.8 lm/m^2.

hydrophilic emulsifier — see *emulsifier*

immersion rinse — a means of removing surface penetrant, in which the test part is immersed in a tank of either water or remover

immersion rinse — a means of removing excess penetrant in which the test parts are dipped into an agitated tank of water or remover

inspection — visual examination of the test part after completion of the liquid penetrant processing steps

lipophilic emulsifier — see *emulsifier lipophilic*

liquid penetrant examination — a nondestructive test that uses suitable liquids that penetrate discontinuities open to the surface of solid materials and, after appropriate treatment, indicate the presence of discontinuities

overemulsification — excessive emulsifier dwell time which results in the removal of penetrants from some discontinuities

overwashing — too long or too vigorous washing, or both, which results in removal of penetrants from some discontinuities

penetrant — a solution or suspension of dye

penetrant comparator — an intentionally flawed specimen having separate but adjacent areas for the application of different liquid penetrant materials so that a direct comparison of their relative effectiveness can be obtained

NOTE 16 — It can also be used to evaluate liquid penetrant techniques, liquid penetrant systems, or test conditions.

penetrant, fluorescent — a penetrant that emits visible radiation when excited by black light

penetrant, post emulsifiable — a liquid penetrant that requires the application of a separate emulsifier to render the excess surface penetrant water-washable

penetrant, solvent-removable — a liquid penetrant so formulated that most of the excess surface penetrant can be removed by wiping with a lint-free material, with the remaining surface penetrant traces removable by further wiping with a lint-free material lightly moistened with solvent remover

penetrant, visible — a liquid penetrant that is characterized by an intense color, usually red

penetrant, water-washable — a liquid penetrant with a built-in emulsifier

penetration time — same as *dwell time*

pooling — the existence of excessive amounts of penetrant, emulsifier, or developer in an incompletely drained area

post-cleaning — the removal of residual liquid penetrant examination materials from the test part after the penetrant examination has been completed

post emulsification — a penetrant removal technique employing a separate emulsifier

precleaning — the removal of surface contaminants from the test part so that they will not interfere with the examination process

rinse — the process of removing liquid penetrant examination materials from the surface of a test part by means of washing or flooding with another liquid, usually water. The process is also termed *wash.*

solvent remover — a volatile liquid penetrant used to remove excess penetrant from the surface being examined

temperature envelope — the temperature range over which a particular penetrant inspection test will operate

viscosity — the property of a fluid that presents a resistance to shearing flow

visible light — electromagnetic radiation in the 400–700 (4000–7000 Å) wavelength range

visual adaptation — the adjustment of the eyes when one passes from a bright to a darkened place

wash — same as *rinse*

water tolerance — the amount of water that a penetrant or emulsifier can absorb before its effectiveness is impaired

wetting action — the ability of a liquid to spread over and adhere to solid surfaces

10. Magnetic Particle Examination

ammeter shunt — a low-resistance precision resistor with high current carrying capacity connected in parallel with an ammeter

ampere turns — the product of the number of turns of a coil and the current in amperes flowing through the coil

arc strikes — localized burn damage to a part from an arc caused by making or breaking an energized electrical circuit

background — in magnetic particle examination, the appearance of the surface of the test part against which indications are viewed

bath — see *suspension*

bipolar field — see *field, bipolar*

black light — electromagnetic radiation in the near ultraviolet range of wavelength (330 to 390 nm) (3300 to 3900 Å)

black light filter — a filter that transmits near ultraviolet radiation while absorbing other wavelengths

carrier fluid — the fluid in which fluorescent and nonfluorescent magnetic particles are suspended to facilitate their application

central conductor — a conductor passed through a hollow part and used to produce circular magnetization within the part

circular field — see *field, circular*

circular magnetization — the magnetization in a part resulting from current passed directly through the part or through a central conductor

coercive force — the magnetizing force at which the magnetic flux density is equal to zero. The corresponding field intensity value is indicative of the ease of difficulty or demagnetization.

coil method — a method of magnetization in which part, or whole, of the component is encircled by a current-carrying coil

coil technique — a technique of magnetization in which all, or a portion, of the part is encircled by a current-carrying coil

conditioning agent — an additive to a water suspension that will impart specific properties such as proper wetting, particle dispersion, or corrosion resistance

contact head — electrode assembly used to clamp and support a part to facilitate passage of electrical current through the part for circular magnetization

contact pad — replaceable metal pad, usually of copper braid, placed on electrodes to give good electrical contact, thereby preventing damage, such as arc strikes, to the part under test

continuous method — with relation to magnetic particle inspection: a method wherein the indicating medium is applied while the magnetizing force is present.

core (of an electromagnetic inspection circuit) — that part of the magnetic circuit which is within the electrical winding

Curie point — the temperature at which ferromagnetic materials can no longer be magnetized by outside forces, and at which they lose their residual magnetism [approximately 1,200 to 1,600°F (649 to 871°C) for many metals]

current flow method — a method of magnetizing by passing a current through a component via prods or contact heads. The current may be alternating, rectified alternating, or direct.

current induction method — a method of magnetizing in which a circulating current is induced in a ring component by the influence of a fluctuation magnetic field that links the component

dark adaptation — the adjustment of the eyes when one passes from a bright to a darkened place

demagnetization — the reduction of residual magnetism to an acceptable level

diffuse indications — indications that are not clearly defined as, for example, indications of subsurface defects

direct contact magnetization — a technique of magnetizing in which the current is passed through a part via prods or contact heads

dry method — magnetic particle inspection in which the ferromagnetic particles employed are in the dry powder form

dry powder — finely divided ferromagnetic particles suitably selected and prepared for magnetic particle inspection

dry technique — in magnetic particle examination, the examination technique in which the ferromagnetic particles are applied in the dry powder form

electromagnet — a soft iron core surrounded by a coil of wire that temporarily becomes a magnet when an electric current flows through the wire

energizing cycle — the application of a magnetizing force to a conductor

examination medium — a powder or suspension of magnetic particles that is applied to a magnetized test surface to determine the presence or absence of surface or slightly subsurface discontinuities

ferromagnetic — a term applied to materials that can be magnetized or strongly attracted by a magnetic field

field, bipolar — longitudinal magnetic field within a part that has two poles

field, circular magnetic — generally, the magnetic field surrounding any electrical conductor or part resulting from a current being passed through the part or conductor from one end to another

field, longitudinal magnetic — magnetic field wherein the flux lines traverse the component in a direction essentially parallel with its longitudinal axis

field, magnetic — the space, within and surrounding a magnetized part or a conductor carrying current, in which the magnetic force is exerted

field, magnetic leakage — the magnetic field that leaves or enters the surface of a part at a discontinuity or change in section configuration of a magnetic circuit

field, residual magnetic — the field that remains in a piece of magnetizable material after the magnetizing force has been removed

field, resultant magnetic — (sometimes called vector): a magnetic field that is the result of two magnetizing forces impressed upon the same area of a magnetizable object

field strength — see *magnetic field strength*

fill factor — in magnetic particle examination, the ratio of the cross-sectional area of the part being tested to the cross-sectional area of the encircling coil

flash magnetization — magnetization by a current flow of very brief duration

flash point — the lowest temperature at which vapors above a volatile combustible substance ignite in air when exposed to a flame

fluorescence — the emission of visible radiation by a substance as the result of, and only during, the absorption of black light radiation

fluorescent examination method — the magnetic particle examination method employing a finely divided fluorescent ferromagnetic inspection medium

fluorescent magnetic particle inspection — the magnetic particle inspection process employing a finely divided fluorescent ferromagnetic inspection medium that fluoresces when activated by black light [3200 to 4000 Å (320 to 400 nm)]

flux density, magnetic — the strength of a magnetic field, expressed in flux lines per unit area

flux leakage field — the magnetic field that leaves or enters the surface of a part as the result of a discontinuity or a change in section

flux lines — see *lines of force*

flux penetration — the depth to which a magnetic flux exists in a part

full-wave direct current (FWDC) — a rectified three-phase alternating current

furring — buildup or bristling of magnetic particles due to excessive magnetization of the component under examination resulting in a furry appearance

half-wave current (HW) — a rectified single-phase alternating current that produces a pulsating unidirectional field

hysteresis — *(1)* the lagging of the magnetic effect when the magnetic force acting upon a ferromagnetic body is changed *(2)* the phenomenon exhibited by a magnetic system wherein its state is influenced by its previous history

indirect magnetization — magnetization induced in a part when no direct electrical contact is made

induced current method — see *current induction method*

induced field — see *indirect magnetization*

inherent fluorescence — fluorescence that is an intrinsic characteristic of a material

inspection medium — see *examination medium*

leakage field — see *field, magnetic leakage*

leeches — permanent magnets or electromagnets that are attached to the electrodes carrying magnetizing current and that are strong enough to hold electrode contact firmly

light intensity — the light energy reaching a unit area of surface per unit time

lines of force — a conceptual representation of magnetic flux based upon the line pattern produced when iron filings are sprinkled on paper laid over a permanent magnet

local magnetization — magnetization of a prescribed volume or surface of a part

longitudinal magnetization — a magnetic field wherein the lines of force traverse the part in a direction essentially parallel with its longitudinal axis

magnet, permanent — see *permanent magnet*

magnetic field — the volume within and surrounding either a magnetized part or a current-carrying conductor wherein a magnetic force is exerted

magnetic field indicator — a pocket meter that is used to locate or determine the relative intensity of leakage field emanating from a part

magnetic field meter — an instrument designed to measure the flux density of magnetic fields

magnetic field strength — the measured intensity of a magnetic field at a point, expressed in oersteds or amperes per metre

magnetic hysteresis — in a magnetic material, as iron, a lagging in the values of resulting magnetization due to a changing magnetic force. (See also *hysteresis.*)

magnetic particle examination — a nondestructive test method utilizing magnetic leakage fields and suitable indicating materials to disclose surface and near-surface discontinuity indications

magnetic particle examination flaw indications — the accumulation of ferromagnetic particles along the areas of flaws or discontinuities due to the distortion of the magnetic lines of force in those areas

magnetic particle field indicator — an instrument, typically a bi-metal (for example, carbon steel and copper) octagonal disk, containing artificial flaws used to verify the adequacy or direction, or both, of the magnetizing field

magnetic particles — finely divided ferromagnetic material capable of being individually magnetized and attracted to distortion in a magnetic field

magnetic pole — one of two or more areas of flux leakage on a part

magnetic writing — a form of nonrelevant indication sometimes caused when the surface of a magnetized part comes in contact with another piece of ferromagnetic material

magnetization, circular — see *field, circular*

magnetization, longitudinal — see *field, longitudinal*

magnetizing current — the flow of either alternating or direct current used to induce magnetism into the part being inspected

magnetizing force — the magnetizing field applied to a ferromagnetic material to induce magnetization

multidirectional magnetization — the alternative application of magnetic fields in different directions during the same time frame

near surface discontinuity — a discontinuity not open to, but lying near, the surface of a part undergoing examination which produces broad, fuzzy, lightly held powder patterns

overall magnetization — magnetization of an entire part with a single energizing cycle

permanent magnet — a magnet that retains a high degree of magnetization virtually unchanged for a long period of time (characteristic of materials with high retentivity)

permeability — the ratio of flux density produced to magnetizing force (the ease with which a material can become magnetized)

pole — the area on a magnetized part from which the magnetic field is leaving or returning into the part

polymer technique — the examination technique in which a polymer is used as the particle suspension vehicle

powder — see *dry powder*

powder blower — a compressed air device used to apply magnetic powder over the surface of a part undergoing inspection

prods — hand-held electrodes

quick break — a sudden interruption of the magnetizing current

residual magnetic field — the field that remains in ferromagnetic material after the magnetizing force has been removed

residual technique — the application of the magnetic particles after the magnetizing force has been discontinued

resultant field — see *field, resultant*

retentivity — the ability of a material to retain a portion of the applied magnetic field after the magnetizing force has been removed

saturation, magnetic — the total magnetization produced in a ferromagnetic material, at which point the incremental permeability has progressively decreased to approach unity

sensitivity — the degree of capability of a magnetic particle examination technique for indicating surface or near surface discontinuities in ferromagnetic materials

shot — a short energizing cycle in a magnetic particle examination

skin effect — the phenomenon that causes the magnetization produced by alternating current to be contained near the surface of a ferromagnetic part

solenoid — an electrical conductor formed into a coil

subsurface discontinuity — any defect that does not open onto the surface of the part in which it exists

surge magnetization — use of a high initial current for a short period (less than a second), then a continuous reduced current while the inspection medium is applied

suspension — a two-phase system consisting of a finely divided solid dispersed in a liquid

swinging field — see *multidirectional magnetization*

test piece — a specimen containing known artificial or natural defects used for checking the efficiency of magnetic particle flaw detection processes

test ring — a ring specimen containing artificial subsurface discontinuities which is used to evaluate and compare the overall performance and sensitivity of magnetic particle examination techniques

through-coil technique — see *coil technique*

true continuous technique — magnetic particle examination in which the magnetizing current is applied prior to the application of the magnetic particles and is maintained without interruption throughout the examination

vehicle — a liquid medium for the suspension of magnetic particles

visible light — radiant energy generated in 400 to 700 nm (4000 to 7000 Å) wavelength range

water break test — a quality control test of conditioned water

wet slurry technique — a magnetic particle examination technique in which the magnetic particles are suspended in a high-viscosity vehicle

wet technique — the examination technique in which the magnetic particles are suspended in a liquid vehicle

white light — see *visible light*

yoke — a magnet that induces a magnetic field in the area of a part that lies between its poles. Yokes may be permanent magnets or either alternating-current or direct-current electromagnets

yoke magnetization — a longitudinal magnetic field induced in a part, or in an area of a part, by means of an external electromagnet shaped like a yoke

11. Neutron Radiology

activation — the process of causing a substance to become artificially radioactive by subjecting it to bombardment by neutrons or other particles

attenuation coefficient — related to the rate of change in the intensity of a beam of radiation as it passes through matter. See *linear and mass attenuation coefficient.*

attenuation cross section — the probability, expressed in barns, that a neutron will be totally absorbed by the atomic nucleus

barn — a unit of area used for expressing the area of nuclear cross sections: 1 barn = 10^{-24} cm^2.

cadmium ratio — the ratio of the neutron reaction rate measured with a given bare neutron detector to the reaction rate measured with an identical neutron detector enclosed by a particular cadmium cover and exposed in the same neutron field at the same or an equivalent spatial location

NOTE 17 — In practice, meaningful experimental values can be obtained in an isotropic neutron field by using a cadmium filter approximately 1-mm thick.

cassette — a light-tight device for holding film or conversion screens and film in close contact during exposure

contrast agent — a material added to a component to enhance details by selective absorption of the incident radiation

conversion screen — a device that converts the imaged neutron beam to radiation or light that exposes the radiographic film

cross section — the apparent cross-sectional area of the nucleus as calculated on the basis of the probability of occurrence of a reaction by collision with a particle. It does not necessarily coincide with the geometrical cross-sectional area πr^2. It is given in units of area, 1 barn = 10^{-24} cm^2.

direct exposure imaging — in the direct exposure imaging method, the conversion screen and image recorder are simultaneously exposed to the neutron beam

electron volt — the kinetic energy gained by an electron after passing through a potential difference of 1 V

facility scattered neutrons — neutrons scattered in the facility that contribute to the film exposure

γ — effective gamma content. γ is the percent background film darkening caused by low-energy photon radiation absorbed by pair production in 2 mm of lead

gamma ray — electromagnetic radiation having its origin in an atomic nucleus

half-life — the time required for one half a given number of radioactive atoms to undergo decay

half-value layer — the thickness of an absorbing material required to reduce the intensity of a beam of incident radiation to one-half of its original intensity

image quality indicator — a device or combination of devices whose image or images on a neutron radiograph provide visual or quantitative data, or both, concerning the radiographic sensitivity of the particular neutron radiograph

indirect exposure — a method in which only a gamma-insensitive conversion screen is exposed to the neutron beam. After exposure, the conversion screen is placed in contact with the image recorder.

L/D ratio — one measure of the resolution capability of a neutron radiographic system. It is the ratio of the distance between the entrance aperture and the image plane (*L*) to the diameter of the entrance aperture (*D*).

linear attenuation coefficient — a measure of the fractional decrease in radiation beam intensity per unit of distance traveled in the material (cm^{-1})

low-energy photon radiation — gamma- and X-ray photon radiation having energy less than 200 keV (excluding visible and ultraviolet light)

mass attenuation coefficient — a measure of the fractional decrease in radiation beam intensity per unit of surface density $cm^2 \cdot gm^{-1}$

moderator — a material used to slow fast neutrons. Neutrons are slowed down when they collide with atoms of light elements such as hydrogen, deuterium, beryllium, and carbon

NC — effective thermal neutron content or neutron radiographic contrast. NC is the percent background film exposure due to unscattered thermal neutrons.

neutron — a neutral elementary particle having an atomic mass close to 1. In the free state outside of the nucleus, the neutron is unstable having a half-life of approximately 10 min.

neutron radiography — the process of producing a radiograph using neutrons as the penetrating radiation

object scattered neutrons — neutrons scattered by the test objects that contribute to the film exposure

P — effective pair production content. *P* is the percent background exposure caused by pair production in 2 mm of lead.

pair production — the process whereby a gamma photon with energy greater than 1.02 MeV is converted directly into matter in the form of any electron-positron pair. Subsequent annihilation of the positron results in the production of two 0.511 MeV gamma photons.

process control radiograph — a radiograph which images a beam purity indicator and sensitivity indicator under identical exposure and processing procedures as the test object radiograph. A process control radiograph may be used to determine image quality parameters in circumstances of large or unusual test object geometry.

radiograph — a permanent, visible image on a recording medium produced by penetrating radiation passing through the material being tested

radiographic inspection — the use of X rays or nuclear radiation, or both, to detect discontinuities in material, and to present their images on a recording medium

radiography — the process of producing a radiograph using penetrating radiation

radiological examination — the use of penetrating ionizing radiation to display images for the detection of discontinuities or to help ensure integrity of the part

radiology — the science and application of X rays, gamma rays, neutrons, and other penetrating radiations

radioscopic inspection — the use of penetrating radiation and radioscopy to detect discontinuities in material

radioscopy — the electronic production of a radiological image that follows very closely the changes with time of the object being imaged

real-time radioscopy — radioscopy that is capable of following the motion of the object without limitation of time

S — effective scattered neutron content. *S* is the percent background film darkening caused by scattered neutrons.

scattered neutrons — neutrons that have undergone a scattering collision but still contribute to film exposure

sensitivity value — the value determined by the smallest standard discontinuity in any given sensitivity indicator observable in the radiographic image. Values are defined by identification of type of indicator, size of defect, and the absorber thickness on which the discontinuity is observed.

thermalization — the process of slowing neutron velocities by permitting the neutrons to come to thermal equilibrium with a moderating medium

thermalization factor — the inverse ratio of the thermal neutron flux obtained in a moderator, per source neutron

thermal neutrons — neutrons having energies ranging between 0.005 eV and 0.5 eV; neutrons of these energies are produced by slowing down fast neutrons until they are in equilibrium with the moderating medium at a temperature near 20°C.

total cross section — the sum of the absorption and scattering cross sections

vacuum cassette — a light-tight device having a flexible entrance window, which when operated under a vacuum, holds the film and conversion screen in intimate contact during exposure

12. Ultrasonic Examination (E 127, E 494, E 664, and E 804)

A-scan — a method of data presentation utilizing a horizontal baseline that indicates distance, or time, and a vertical deflection from the baseline which indicates amplitude

amplitude — the vertical pulse height of a signal, usually base to peak, when indicated by an A-scan presentation

angle beam — a term used to describe an angle of incidence or refraction other than normal to the surface of the test object, as in angle beam examination, angle beam search unit, angle beam longitudinal waves, and angle beam shear waves

apparent attenuation — the observed ultrasound energy loss. In addition to the true loss, the apparent attenuation may also include losses attributable to instrumentation, specimen configuration, beam divergence, interface reflections, and measurement procedure. (E 664)

area amplitude response curve — a curve showing the changes in amplitude at normal incidence from planar reflectors of different areas located at equal distances from the search unit in an ultrasonic-conducting medium

attenuation — a factor that describes the decrease in ultrasound intensity with distance. Normally expressed in decibel per unit length.

NOTE 18 — The attenuation parameter is sometimes expressed in nepers (Np) per unit length. The value in decibels (dB) is 8.68 times

the value in nepers. If the loss over a path is 1 Np, then the amplitude has fallen to 1/e of its initial value (e = 2.7183. . .). (E 664)

attenuator — a device for altering the amplitude of an ultrasonic indication in known increments, usually decibels

B-scan presentation — a means of ultrasonic data presentation which displays a cross section of the specimen indicating the approximate length (as detected per scan) of reflectors and their relative positions

back reflection — indication of the echo from the far boundary of the material under test

back surface — the end of a reference block that is opposite the entry surface (E 127)

base line — the time of flight or distance trace (horizontal) across the A-scan CRT display (for no signal condition)

beam axis — the acoustic centerline of a search unit's beam pattern as defined by the locus of points of maximum sound pressure in the far field, and its extension into the near field

beam spread — a divergence of the ultrasonic beam as the sound travels through a medium

bottom echo — see *back reflection*

bubbler — a device using a liquid stream to couple an ultrasonic beam to the test piece

C-scan — an ultrasonic data presentation which provides a plain view of the test object, and discontinuities therein

collimator — a device for controlling the size and direction of the ultrasonic beam

compressional wave — see *longitudinal wave*

contact testing — a technique in which the search unit makes contact directly with the test piece through a thin layer of couplant

continuous wave — a constant flow of ultrasonic waves, as opposed to pulsed

control echo — reference signal from a constant reflecting surface, such as a back reflection

corner effect — the reflection of an ultrasonic beam directed at normal incidence to the line of intersection of two perpendicular planes

couplant — a substance used between the search unit and test surface to permit or improve transmission of ultrasonic energy

critical angle — the incident angle of the ultrasonic beam beyond which a specific refracted wave no longer exists

cross talk — the signal leakage (acoustic or electric) across an intended acoustic or electric barrier

crystal (see *transducer)* — the piezoelectric element in an ultrasonic search unit. The term is used to describe single crystal piezoelectrics as well as polycrystalline piezoelectrics, such as ferroceramics.

DAC (distance amplitude correction) (swept gain, time corrected gain, time variable gain, etc.) — electronic change of amplification to provide equal amplitude from equal reflectors at different depths

damping, search unit — limiting the duration of a signal from a search unit subject to a pulsed input by electrically or mechanically decreasing the amplitude of successive cycles

dB control — a control that adjusts the amplitude of the display signal in dB units

dead zone — the distance in the material from the surface of the test object to the depth at which a reflector can first be resolved under specified conditions. It is determined by the characteristics of the search unit, the ultrasonic test instrumentation, and the test object

decibel (dB) — twenty times the base ten logarithm of the ratio of two ultrasonic signal amplitudes: dB = 20 $\log_{10}$ (amplitude ratio)

delayed sweep — an A-scan or B-scan presentation in which an initial part of the time scale is not displayed

DGS (distance gain size-German AVG) — distance amplitude curves permitting prediction of reflector size compared to the response from a back surface reflection

distance amplitude compensation (electronic) — the compensation or change in receiver amplification necessary to provide equal amplitude on the display of the ultrasonic flaw detector for reflectors of equal area which are located at different depths in the material

distance amplitude response curve — a curve showing the relationship between the different distances and the amplitudes of ultrasonic response from targets of equal size in an ultrasonic response from targets of equal size in an ultrasonic transmitting medium (E 127)

distance linearity range — the range of horizontal deflection in which a constant relationship exists between the incremental horizontal displacement of vertical indications on the A-scan presentation and the incremental time required for reflected waves to pass through a known length in a uniform transmission medium (E 494)

dual search unit — a search unit containing two elements: one a transmitter, the other a receiver

dynamic range — a measure of the capability of a test system to accept input signals of varying magnitudes, given by the ratio of the maximum to minimum input signals which at constant gain will produce distor-

tion-free outputs having discernable changes with incremental variations in input

NOTE 19 — Dynamic range may be stated as the numerical value of the ratio, however, this is usually expressed in decibels.

NOTE 20 — When the output indications can be related to the size of recognized targets, such as flat-bottomed holes, dynamic range is sometimes expressed in terms of the maximum and minimum hole sizes that can be displayed.

echo — indication of reflected energy

far field — the zone of the beam where equal reflectors give exponentially decreasing amplitudes with increasing distance

focused beam — converging energy of the sound beam at a specified distance

frequency (fundamental) — in resonance testing, the frequency at which the wave length is twice the thickness of the examined material

frequency (inspection) — effective ultrasonic wave frequency of the system used to inspect the material

frequency (pulse repetition) — the number of times per second an electro-acoustic search unit is excited by the pulse generator to produce a pulse of ultrasonic energy. This is also called pulse repetition rate.

gap scanning — short fluid column coupling technique

gate — an electronic means of selecting a segment of the time range for monitoring or further processing

grazing incidence — immersion inspection with the beam directed at a glancing angle to the test surface

harmonics — those vibrations which are integral multiples of the fundamental frequency

holography (acoustic) — an inspection system using the phase interface between the ultrasonic wave from an object and a reference signal to obtain an image of reflectors in the material under test

immersion testing — an ultrasonic examination method in which the search unit and the test part are submerged (at least locally) in a fluid, usually water

impedance (acoustic) — a mathematical quantity used in computation of reflection characteristics at boundaries; product of wave velocity and material density

indication — that which marks or denotes the presence of a reflector

initial pulse — the response of the ultrasonic system display to the transmitter pulse (sometimes called main bang)

interface — the boundary between two materials

Lamb wave — a specific mode of propagation in which the two parallel boundary surfaces of the material under examination (such as a plate or the wall of a tube) establish the mode of propagation. The Lamb wave can be generated only at particular values of frequency, angle of incidence, and material thickness. The velocity of the wave is dependent on the mode of propagation and the product of the material thickness and the examination frequency.

linearity (amplitude) — a measure of the proportionality of the amplitude of the signal input to the receiver, and the amplitude of the signal appearing on the display of the ultrasonic instrument or on an auxiliary display

linearity (time or distance) — a measure of the proportionality of the signals appearing on the time or distance axis of the display and the input signals to the receiver from a calibrated time generator or from multiple echos from a plate of material of known thickness

longitudinal wave — those waves in which the particle motion of the material is essentially in the same direction as the wave propagation (E 494)

loss of back reflection — an absence or significant reduction in the amplitude of the indication from the back surface of the part under examination

markers — the electronically generated time pulses or other indicators that are used on the instrument display to measure distance or time

mode — the type of ultrasonic wave propagating in the materials as characterized by the particle motion (for example, longitudinal, transverse, etc.)

mode conversion — phenomenon by which an ultrasonic wave that is propagating in one mode can reflect or refract at an interface to form ultrasonic wave(s) of other modes

multiple back reflections — successive reflections from the back surface of the material under examination

multiple reflections — successive echoes of ultrasonic energy between two surfaces

near field — the region of the ultrasonic beam adjacent to the transducer and having complex beam profiles. Also known as the Fresnel zone.

noise — any undesired signal (electrical or acoustic) that tends to interfere with the reception, interpretation, or processing of the desired signal

normal incidence (also see straight beam) — a condition in which the axis of the ultrasonic beam is perpendicular to the entry surface of the part under examination

penetration depth — the maximum depth in a material from which usable ultrasonic information can be obtained and measured

plate wave — see *Lamb wave*

probe — see *search unit*

pulse — a short wave train of mechanical vibrations

pulse echo method — an inspection method in which the presence and position of a reflector are indicated by the echo amplitude and time

pulse length — a measure of the duration of a signal as expressed in time or number of cycles

pulse repetition rate — see *frequency (pulse repetition)*

pulse tuning — a control used on some ultrasonic examination equipment to optimize the response of the search unit and cable to the transmitter by adjusting the frequency spectrum of the transmitted pulse

radio frequency (r-f) display — the display of an unrectified signal on the CRT or recorder

range — the maximum sound path length that is displayed

Rayleigh wave — an ultrasonic surface wave in which the particle motion is elliptical and the effective penetration is approximately one wavelength

reference block — a block that is used both as a measurement scale and as a means of providing an ultrasonic reflection of known characteristics

reflection — see *echo*

reflector — an interface at which an ultrasonic beam encounters a change in acoustic impedance and at which at least part of the energy is reflected

reject (suppression) — a control for minimizing or eliminating low amplitude signals (electrical or material noise) so that larger signals are emphasized

resolution — the ability of ultrasonic equipment to give simultaneous, separate indications from discontinuities having nearly the same range and lateral position with respect to the beam axis

resonance method — a technique in which continuous ultrasonic waves are varied in frequency to identify resonant characteristics in order to discriminate some property of a part such as thickness, stiffness, or bond integrity

saturation — a condition in which an increase in input signal produces no increase in amplitude on the display

saturation level — see *vertical limit*

scanning — the movement of a search unit relative to the test piece in order to examine a volume of the material

scanning index — the distance the search unit is moved between scan paths after each traverse of the part

scattered energy — energy that is reflected in a random fashion by small reflectors in the path of a beam of ultrasonic waves

scattering — the dispersion, deflection, or redirection of the energy in an ultrasonic beam caused by small reflectors in the material being examined

Schlieren system — an optical system used for visual display of an ultrasonic beam passing through a transparent medium

SE probe — see *dual search unit (twin probe)*

search unit — an electro-acoustic device used to transmit or receive ultrasonic energy, or both. The device generally consists of a nameplate, connector, case, backing, piezo-electric element, wearface, or lens, or wedge.

sensitivity — a measure of the smallest ultrasonic signal which will produce a discernible indication on the display of an ultrasonic system

shadow — a region in a body that cannot be reached by ultrasonic energy traveling in a given direction because of the geometry of the body or a discontinuity in it

shear wave — wave motion in which the particle motion is perpendicular to the direction of propagation

shear wave search unit (Y cut quartz search unit) — a straight beam search unit used for generating and detecting shear waves

signal-to-noise ratio — the ratio of the amplitude of an ultrasonic indication to the amplitude of the maximum background noise

skip distance — in angle beam examination, the distance along the test surface, from sound entry point to the point at which the sound returns to the same surface. It can be considered the top surface distance of a complete vee path of sound in the test material.

straight beam — a vibrating pulse wave train traveling normal to the test surface

suppression — see *reject (suppression)*

surface wave — see *Rayleigh wave*

sweep — the uniform and repeated movement of an electron beam across the CRT

swept gain — see *DAC*

testing, ultrasonic — a nondestructive method of examining materials by introducing ultrasonic waves into, through, or onto the surface of the article being examined and determining various attributes of the material from effects on the ultrasonic waves

test surface — that surface of a part through which the ultrasonic energy enters or leaves the part

through transmission technique — a test procedure in which the ultrasonic vibrations are emitted by one search unit and received by another at the opposite surface of the material examined

transducer — an electroacoustical device for converting electrical energy into acoustical energy and vice versa. See also *crystal.*

transverse wave — see *shear wave.*

transverse wave — wave motion in which the particle displacement at each point in a material is perpendicular to the direction of propagation (E 494)

true attenuation — that portion of the observed ultrasound energy loss which is intrinsic to the medium through which the ultrasound propagates. True attenuation losses may be attributed to the basic mechanisms of absorption and scattering. (E 664)

ultrasonic — pertaining to mechanical vibrations having a frequency greater than approximately 20,000 Hz

ultrasonic noise level — the large number of unresolved indications resulting from structure or possibly from numerous small discontinuities, or both (E 127)

ultrasonic spectroscopy — analysis of the frequency spectrum of an ultrasonic wave

vee path — the angle-beam path in materials starting at the search-unit examination surface, through the material to the reflecting surface, continuing to the examination surface in front of the search unit, and reflection back along the same path to the search unit. The path is usually shaped like the letter V.

vertical limit — the maximum readable level of vertical indications determined either by an electrical or a physical limit of an A-scan presentation

video presentation — display of the rectified, and usually filtered, r-f signal

water path — the distance from the transducer to the test surface in immersion or water column testing

wave front — a continuous surface drawn through the most forward points in a wave disturbance which have the same phase

wave train — a succession of ultrasonic waves arising from the same source, having the same characteristics, and propagating along the same path

wedge — in ultrasonic angle-beam examination by the contact method, a device used to direct ultrasonic energy into the material at an angle

wheel search unit — an ultrasonic device incorporating one or more piezoelectric elements mounted inside a liquid-filled flexible tire. The beam is coupled to the test surface through the rolling contact area of the tire.

wrap around — the display of misleading reflections from a previously transmitted pulse, caused by an excessively high pulse-repetition frequency

13. Infrared Examination (E 1213)

absorptance, α — the ratio of radiant flux absorbed by a surface to that incident upon it

apparent temperature — the temperature of an object as determined solely from the measured radiance, assuming an emissivity of unity

background radiation — all radiation received by the infrared sensing device that was not emitted by the specified area of the surface being examined

background, target — that portion of the background which is confined to the field of view

blackbody — an ideal thermal radiator (emissivity = 1.0) that emits and absorbs all of the available thermal radiation at a given temperature

blackbody equivalent temperature — the apparent temperature of an object as determined from the measured radiance and the assumption that it is an ideal blackbody with emissivity of 1.0

differential blackbody — an apparatus for establishing two parallel isothermal planar zones of different temperatures, and with effective emissivities of 1.0 (E 1213)

emissivity, ϵ — the ratio of the radiance of a body at a given temperature to the corresponding radiance of a blackbody at the same temperature

extended source — a source of infrared radiation whose image completely fills the field of view of a detector

NOTE 21 — The irradiance is independent of the distance from the source to the region of observation. In practice, sources that are not extended sources are considered to be point sources; see *point source.*

field of view (FOV) — the shape and angular dimensions of the cone or the pyramid which define the object space imaged by the system; for example, rectangular, 4 deg. wide by 3 deg. high

imaging line scanner — an apparatus that scans in a single dimension and is moved perpendicular to the scan direction to produce a two-dimensional thermogram of a scene

infrared imaging system — an apparatus that converts the two-dimensional spatial variations in infrared radiance from any object surface into a two-dimensional thermogram of the same scene, in which variations in radiance are displayed in gradations of gray tone or in color

infrared reflector — a material with a reflectance in the infrared region as close as possible to 1.00

infrared sensing device — one of a wide class of instruments used to display or record, or both, information related to the thermal radiation received from any object surfaces viewed by the instrument. The instrument varies in complexity from spot radiometers to two-dimensional real-time imaging systems.

infrared thermographer — the person qualified or trained to use infrared imaging radiometer

infrared thermography — see *thermography, infrared*

instantaneous field of view (IFOV) — for a scanning system, the angular dimensions in object space within which objects are imaged by an individual detector (unit = deg. or rad)

DISCUSSION — The IFOV is equivalent to the horizontal and vertical fields of view of the individual detector. For small detectors, the detector angular subtenses or projections, α and β, are defined by $\alpha = a/f$ and $\beta = b/f$ where a and b are the horizontal and vertical dimensions of the detector and f is the effective focal length of the optic. (IFOV may also be expressed as a solid angle in units of sr.)

irradiance, E — the radiant flux (power) per unit area incident on a given surface (unit = W/m^2)

limiting resolution — the highest spatial frequency of a target that an imaging sensor is able to resolve

line scanner — an apparatus that scans along a single line of a scene to provide a one-dimensional thermal profile of the scene

minimum detectable temperature difference (MDTD) — a measure of the compound ability of an infrared imaging system and an observer to detect a target of unknown location at one temperature against a large uniform background at another temperature when displayed on a monitor for a limited time

DISCUSSION — For a given target size, the MDTD is the minimum temperature difference between the target and its background at which the observer can detect the target. The standard target is a circle whose size is given by its angular subtense, and both target and background are isothermal blackbodies.

minimum resolvable temperature difference (MRTD) — a measure of the ability of an infrared imaging system and the human observer to recognize periodic bar targets on a display. The MRTD is the minimum temperature difference between a standard periodic test pattern (7:1 aspect ratio, 4 bars) and its blackbody background at which an observer can resolve the pattern as a four-bar pattern (see Fig. 4).

modulation transfer function (MTF) — in infrared imaging systems, the modulus of a Fourier transform that describes the spatial distribution of the overall attenuation in amplitude of a thermal imaging system

NOTE 22 — MTF is a sensitive function of spatial frequency.

noise equivalent temperature difference (NETD) — the target-to-background temperature difference between a blackbody target and its blackbody background at which the signal-to-noise ratio of a thermal imaging system or scanner is unity

object plane resolution — the dimension in the object plane that corresponds to the product of a system's instantaneous field-of-view and a specified distance from the system to the object

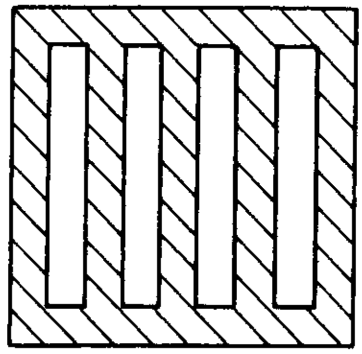


FIG. 4 SCHEMATIC DIAGRAM OF FOUR-BAR PATTERN WITH BACKGROUND, USED TO EVALUATE MINIMUM RESOLVABLE TEMPERATURE DIFFERENCE

point source — a source whose linear dimensions are very small compared with the distance from the source to the region of observation

NOTE 23 — The irradiance varies inversely with the square of the distance; a unique property of point sources.

radiance, L — the flux per unit projected area per unit solid angle leaving a source or, in general, any reference surface. If $d^2\Phi$ is the flux emitted into a solid angle $d\omega$ by a source element of projected area $dA \cos \theta$, the radiance is defined as:

$$L = \frac{d^2\Phi}{d\omega \cdot dA \cos \theta}$$

where, as shown in Fig. 5, θ is the angle between the outward surface normal of the area element dA and the direction of observation (unit = $W/sr \cdot m^2$).

radiant exitance, M — the radiant flux per unit area leaving a surface. That is,

$$M = \frac{d\Phi}{dA}$$

where:

$d\Phi$ = flux leaving a surface element dA (unit = W/m^2).

DISCUSSION — In general, exitance includes emitted, transmitted, and reflected flux.

radiant flux; radiant power, ϕ_e — radiant energy per unit time (unit = W)

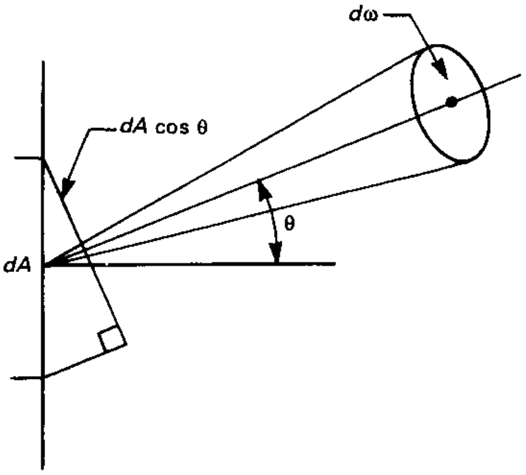


FIG. 5 SCHEMATIC REPRESENTATION OF RADIANCE

radiometer — an instrument for measuring the intensity of radiant energy. In infrared thermography, an apparatus that measures the average apparent temperature of the surface subtended by its field of view.

reflectance — the ratio of the radiant flux reflected from a surface to that incident upon it

reflected temperature — the temperature of the energy incident upon and reflected from the measurement surface of a specimen

spatial frequency — a measure of detail in terms of equivalent, uniformly spaced, cyclical patterns. In an object or image plane, it may be expressed in units of cycles per millimeter (cy/mm) or line pairs per millimeter (lp/mm). In an imaging system, it may be expressed in units of cycles per milliradian (cy/mrad) or line pairs per milliradian (lp/mrad).

thermal resolution — the smallest apparent temperature difference between two blackbodies that can be measured by an infrared sensing device

thermogram — a visual image which maps the apparent temperature pattern of an object or scene into a corresponding contrast or color pattern

thermography, infrared — the process of displaying variations of apparent temperature (variations of temperature or emissivity, or both) over the surface of an object or a scene by measuring variations in infrared radiance

NOTE 24 — In general, *passive thermography* refers to examination of an object or system during its normal operational mode, without the application of any additional energy source for the express purpose of generating a thermal gradient in the object or system; *active thermography* refers to the examination of an object upon intentional application of an external energy source. The energy source (active or passive) may be a source of heat, mechanical energy (vibration or fatigue testing), electrical current, or any other form of energy.

transmittance, τ — the ratio of the radiant flux transmitted through a body to that incident upon it

vibrothermography — a thermographic technique for examining an object in which temperature differences are produced by excitation

14. Optical Holography

amplitude hologram — a recording of the variation of light intensity caused by the interference between the reference beam and the object beam, as light or dark areas on the recording medium. The light and dark interference lines in the recording medium diffract laser light to produce the reconstruction.

beam ratio — the measured intensity of the reference beam divided by the measured intensity of the object beam in the plane of the recording medium

beamsplitter — an optical device for dividing a beam into two or more separate beams

coherence — a property of a beam of electromagnetic radiation in which the phase relationship between any two points across the beam or in time remains essentially constant (see *coherence length*)

coherence length — the path difference between the object beam and the reference beam at which interference fringes reduce in contrast by a factor of $\sqrt{2}/2$ (0.707) from the point of maximum contrast. The coherence length is related to the width of the spectral line emitted from the laser: $L_c = c/\Delta\nu$, where c is the speed of light and $\Delta\nu$ is the bandwidth of the spectral emission line.

exposure — the product of irradiance and time required to produce a suitable pattern on the recording medium

fringe — one of the light or dark bands produced by the interference of the light scattered by the real object and the virtual image of the object

holography (optical) — a technique for recording, and reconstructing, the amplitude and phase distributions of a wave disturbance; widely used as a method of three-dimensional optical image formation. The technique is accomplished by recording the pattern of interference between coherent light reflected from the object of interest (object beam), and light that comes directly from the same source (reference beam).

interference — the variation with distance or time of the amplitude of a wave which results from the

superposition of two or more waves having the same, or nearly the same, frequency

monochromatic — a property of a beam of electromagnetic radiation in which all waves in the beam have the same wavelength

object beam — the portion of laser radiation which illuminates the test object surface, is scattered, and carries object information to the recording medium

object beam angle — the angle between a line from the center of the object to the center of the recording medium and the normal to the center of the recording medium

path length — the distance traveled by the laser radiation from the beam splitter to the recording medium

path length diffrerence — the difference in path length between the object beam and the reference beam

phase hologram — a recording of the variations in light intensity caused by the interference of the reference beam with the object beam as variations in the thickness or index of refraction of the recording medium. The variations in thickness or index refract coherent light to produce the reconstruction.

real image — a reproduction of an object by an optical system which gathers light from an object point and transforms it into a beam that converges toward another point

recording medium — a light-sensitive material which detects the interference between the object beam and the reference beam. Typical recording media used in holography are silver halide film, thermoplastic film, and electronic detectors such as video tubes and CCD arrays.

reference beam — laser radiation impinging directly upon the recording medium through optical components and which typically does not contain information about the test object. In some tests, the reference beam may be reflected or scattered from a portion of the object surface. In this case, any object information contained in the reference beam is cancelled in the object beam by the interference between the object beam and the reference beam.

reference beam angle — the angle formed between the centerline of the reference beam and the normal to the recording medium

speckle — the random interference pattern which results from the illumination of an optically rough surface with coherent radiation. In laser systems, it results in the granular effect which can be seen in a scattered beam.

virtual image — a reproduction of an object by an optical system which gathers light from an object point and transforms it into a beam that appears to diverge from another point

APPENDIX

(Nonmandatory Information)

X1. TERMS DEFINED IN THIS STANDARD

X1.1 The following is an alphabetized list of terms defined in this standard:

Appendix

APPENDIX

APPENDIX I — MANDATORY SUBMITTAL OF TECHNICAL INQUIRIES TO THE BOILER AND PRESSURE VESSEL COMMITTEE

I-100 INTRODUCTION

The ASME Boiler and Pressure Vessel Committee and its Subcommittees, Subgroups, and Working Groups meet regularly to consider revisions of the Code rules, new Code rules as dictated by technological development, Code Cases, and Code interpretations. This Appendix provides guidance to Code users for submitting technical inquiries to the Committee. Technical inquiries include requests for revisions or additions to the Code rules, requests for Code Cases, and requests for Code interpretations.

Code Cases may be issued by the Committee when the need is urgent. Code Cases clarify the intent of existing Code requirements or provide alternative requirements. Code Cases are written as a question and a reply and are usually intended to be incorporated into the Code at a later date. Code interpretations provide the meaning of or the intent of existing rules in the Code and are also presented as a question and a reply. Both Code Cases and Code interpretations are published by the Committee.

The Code rules, Code Cases, and Code interpretations established by the Committee are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design or as limiting in any way the freedom of manufacturers or constructors to choose any method of design or any form of construction that conforms to the Code rules.

As an alternative to the requirements of this Appendix, members of the Committee and its Subcommittees. Subgroups, and Working Groups may introduce requests for Code revisions or additions, Code Cases, and Code interpretations at their respective Committee meetings or may submit such requests to the secretary of a Subcommittee, Subgroup, or Working Group.

Inquiries that do not comply with the provisions of this Appendix or that do not provide sufficient information for the Committee's full understanding may result in the request being returned to the inquirer with no action.

I-200 INQUIRY FORMAT

Submittals to the Committee shall include:

(a) Purpose. Specify one of the following:

(1) Revision of present Code rule(s).

(2) New or additional Code rule(s).

(3) Code Case.

(4) Code interpretation.

(b) Background. Provide the information needed for the Committee's understanding of the inquiry, being sure to include reference to the applicable Code Section, Division, Edition, Addenda, paragraphs, figures, and tables. Preferably, provide a copy of the specific referenced portions of the Code.

(c) Presentations. The inquirer may desire or be asked to attend a meeting of the Committee to make a formal presentation or to answer questions from the Committee members with regard to the inquiry. Attendance at a Committee meeting shall be at the expense of the inquirer. The inquirer's attendance or lack of attendance at a meeting shall not be a basis for acceptance or rejection of the inquiry by the Committee.

I-300 CODE REVISIONS OR ADDITIONS

Requests for Code revisions or additions shall provide the following:

(a) Proposed Revision(s) or Addition(s). For revisions, identify the rules of the Code that require revision and submit a copy of the appropriate rules as they appear in the Code marked up with the proposed revision. For addition, provide the recommended wording referenced to the existing Code rules.

(b) Statement of Need. Provide a brief explanation of the need for the revision(s) or addition(s).

(c) Background Information. Provide background information to support the revision(s) or addition(s) including any data or changes in technology that form the basis for the request that will allow the Committee

to adequately evaluate the proposed revision(s) or addition(s). Sketches, tables, figures, and graphs should be submitted as appropriate. When applicable, identify any pertinent paragraph in the Code that would be affected by the revision(s) or addition(s) and paragraphs in the Code that reference the paragraphs that are to be revised or added.

I-400 CODE CASES

Requests for Code Cases shall provide a *Statement of Need* and *Background Information* similar to that defined in I-300(b) and I-300(c), respectively, for Code revisions or additions. The proposed Code Case should identify the Code Section and Division and be written as a *Question* and a *Reply* in the same format as existing Code Cases.

I-500 CODE INTERPRETATIONS

Requests for Code interpretations shall provide the following:

(a) Inquiry. Provide a condensed and precise question, omitting superfluous background information, and, when possible, composed in such a way that a "yes" or a "no" *Reply,* possibly with brief provisos. The question should be technically and editorially correct.

(b) Reply. Provide a proposed *Reply* that will clearly and concisely answer the *Inquiry* question. Preferably, the *Reply* should be "yes" or "no" with brief provisos.

(c) Background Information. Provide any background information that will assist the Committee in understanding the proposed *Inquiry* and *Reply.*

I-600 SUBMITTALS

Submittals to and responses from the Committee shall meet the following:

(a) Submittal. Inquiries from Code users shall preferably be submitted in typewritten form; however, legible handwritten inquiries will also be considered. They shall include the name, address, telephone number, and a fax number, if available, of the inquirer and be mailed to the following address:

Secretary
ASME Boiler and Pressure Vessel Committee
Three Park Avenue
New York, NY 10016

(b) Response. The Secretary of the ASME Boiler and Pressure Vessel Committee or of the appropriate Subcommittee shall acknowledge receipt of each properly prepared inquiry and shall provide a written response to the inquirer upon completion of the requested action by the Code Committee.

SI UNITS

The 2001 Edition of the Boiler and Pressure Vessel Code is based on U.S. Customary (ft-lb) units of measurement which are to be regarded as the standard. This supplement is provided as a convenience to the Code user and contains SI conversion factors for units contained in the Code.

LIST OF SI UNITS FOR USE WITH ASME BOILER AND PRESSURE VESSEL CODE[1]

Quantity	Unit	Symbol	Other Units or Limitations
Space and Time			
plane angle	radian	rad	degree (decimalized)
length	meter	m	
area	square meter	m^2	
volume	cubic meter	m^3	liter (L) for liquid only (use without prefix other than in milliliter, mL)
time	second	s	minute (min), hour (h), day (d), week, and year
Periodic and Related Phenomena			
frequency	hertz	Hz	revolutions per second (r/s)
rotational frequency	revolutions per second	s^{-1}	revolutions per minute (r/m)
Mechanics			
mass	kilogram	kg	
density	kilogram per cubic meter	kg/m^3	
moment of inertia	kilogram · $meter^2$	$kg \cdot m^2$	
force	newton	N	
moment of force (torque)	newton-meter	N · m	
pressure and stress	pascal	Pa	(pascal = newton per square meter)
energy, work	joule	J	kilowatt-hour (kW · h)
power	watt	W	
impact strength	joule	J	
section modulus	$meter^3$	m^3	
moment of section (second moment of area)	$meter^4$	m^4	
fracture toughness	$Pa \cdot \sqrt{m}$		
Heat			
temperature — thermodynamic [Note (2)]	kelvin	K	degree Celsius (°C)
temperature — other than thermodynamic	degree Celsius	°C	kelvin (K)
linear expansion coefficient	meter per meter-kelvin	K^{-1}	$°C^{-1}$
quantity of heat	joule	J	
heat flow rate	watt	W	
thermal conductivity	watt per meter-kelvin	W/(m · K)	W/(m · °C)
thermal diffusivity	square meter per second	m^2/s	
specific heat capacity	joule per kilogram-kelvin	J/(kg · K)	J/(kg · °C)
Electricity and Magnetism			
electric current	ampere	A	
electric potential	volt	V	
current density	ampere per $meter^2$	A/m^2	
magnetic field strength	ampere per meter	A/m	

NOTES:

(1) Conversion factors between SI units and U.S. customary are given in SI-1, "ASME Orientation and Guide for Use of SI (Metric) Units," and ASTM E 380.

(2) Preferred use for temperature and temperature interval is degrees Celsius (°C), except for thermodynamic and cryogenic work where kelvins may be more suitable. For temperature interval, 1 K = 1°C exactly.

COMMONLY USED CONVERSION FACTORS
(For Others See ASTM E 380) [See Note (1)]

Quantity	To Convert From	To	Multiply by [Note (2)]	
plane angle	degree	rad	1.745 329	E–02
length	in	m	2.54*	E–02
	ft	m	3.048*	E–01
	yd	m	9.144*	E–01
area	in^2	m^2	6.451 6*	E–04
	ft^2	m^2	9.290 304*	E–02
	yd^2	m^2	8.361 274	E–01
volume	in^3	m^3	1.638 706	E–05
	ft^3	m^3	2.831 685	E–02
	US gallon	m^3	3.785 412	E–03
	Imperial gallon	m^3	4.546 09	E–03
	liter	m^3	1.0*	E–03
mass	lbm	kg	4.535 924	E–01
	ton (metric) (mass)	kg	1.000 00*	E+03
	ton (short 2000 lbm)	kg	9.071 847	E+02
force	kgf	N	9.806 65*	E+00
	lbf	N	4.448 222	E+00
bending, torque	kgf · m	N · m	9.806 65*	E+00
	lbf · in	N · m	1.129 848	E–01
	lbf · ft	N · m	1.355 818	E+00
pressure, stress	kgf/m^2	Pa	9.806 65*	E+00
	lbf/ft^2	Pa	4.788 026	E+01
	lbf/in^2 (psi)	Pa	6.894 757	E+03
	$kips/in^2$	Pa	6.894 757	E+06
	bar	Pa	1.0*	E+05
energy, work	Btu (IT) [Note (3)]	J	1.055 056	E+03
	ft · lbf	J	1.355 818	E+00
power	hp (550 ft · lbf/s)	W	7.456 999	E+02
fracture toughness	ksi $\sqrt{in}$	Pa · $\sqrt{m}$	1.098 843	E+06
temperature	°C	K	$t_K = t_C + 273.15$	
	°F	K	$t_K = (t_F + 459.67)/1.8$	
	°F	°C	$t_C = (t_F - 32)/1.8$	
temperature interval	°C	K	1.0*	E+00
	°F	K or °C	5.555 555	E–01

NOTES:

(1) Care should be taken when converting formulas or equations that contain constant terms or factors. The value of these terms must be understood and may also require conversion.

(2)(a) Relationships that are exact in terms of the base units are followed by a single asterisk.

(b) The factors are written as a number greater than 1 and less than 10 with 6 or less decimal places. The number is followed by the letter E (for exponent), a plus or minus symbol, and two digits which indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example: 3.523 907 E–02 is 3.523 907 × 10^{-2} or 0.035 239 07.

(3) International Table

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